METALS AND ALLOYS

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PRODUCTION FABRICATION
TREATMENT APPLICATION

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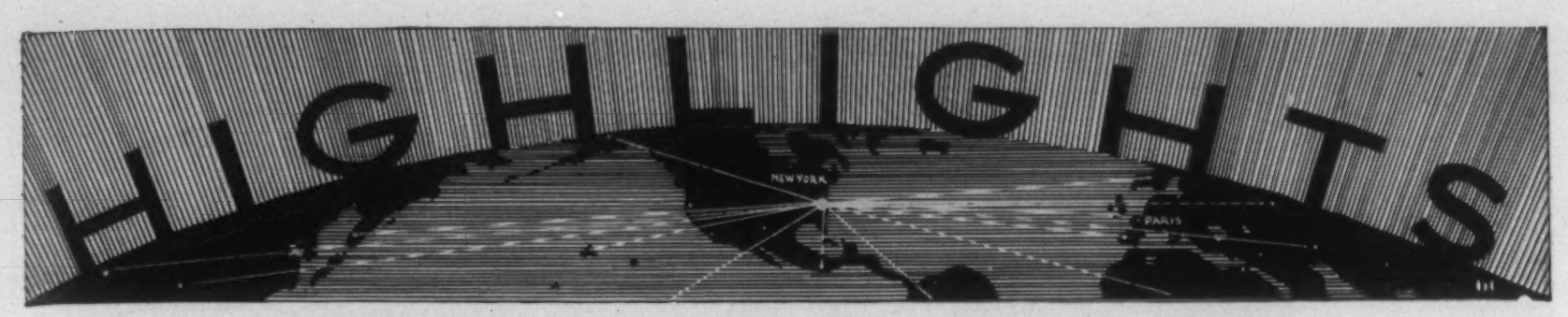


Written by the Abstract Section Editors and the Editorial Staff

DO YOU want to know what metallurgical engineers are saying, the world over? Look in the Current Metallurgical Abstracts. Here are some of the points covered by authors whose articles are abstracted in this issue.

Measuring Grinding Efficiency

An ingenious method involving the coercive force of magnetite for measuring grinding efficiency is reported by Dean (page MA 278 L 8).—J.G.A.

Sand at High Temperatures

Dietert and Valtier (page MA 280 L 2) argue that foundrymen should consider not only the room temperature, but also the high temperature properties of molding sand. Since it is for service at high temperatures, this makes sense.—H.W.G.

Brass (?) in the Cupola

Thews (page MA 280 R 2) alleges that Americans consider the cupola suitable for melting brass. They don't, but they do find it suitable for bronzes. Thews omits to consider that the loss of zinc from miscellaneous scrap is in this case a virtue, as it makes possible the use of cheap raw material without loss of the more valuable elements, tin and copper.—H.W.G.

More Gases in Metals

Raub and co-workers bring out clearly that different gases affect different copper-base alloys differently and that one cannot draw sweeping generalizations, but instead must study specific cases (page MA 280 R 4).—H.W.G.

Flame in the Open-Hearth

Semikin (page MA 283 L 2) philosophizes at considerable length on the effects of speed and distribution of the flame in the open-hearth furnace.—H.W.G.

Soft Pulleys Recommended

According to the British Wire Ropes Research Committee, it is wise to use a soft enough pulley so that the wire rope cuts its own groove without itself being worn; hence ordinary cast iron is favored over chilled iron, and plastic wood, bedded into an undercut groove is found satisfactory (page MA 285 L 1).—H.W.G.

Material for Rolls

Lueg and Pomp (page MA 286 L 5) conclude that the material from which rolling mill rolls are made has no influence, only the quality of the roll surface affecting the finish of the product.—H.W.G.

Aging of Steels

Present theories of the aging of steels are reviewed by Sauveur and Galibourg (Page MA 291 L 4).—H.W.G.

The Open-Hearth is Examined

In an exhaustive and valuable series of articles (page MA 292 L 3) Buell studies in detail the design and construction of modern open-hearth furnaces.—H.W.G.

Reactions in Sheathed Resistor Wire

Navias (page MA 292 R 2) gives interesting data on the behavior of NiCr and NiCrFe resistor wire in contact with MgO, in moist and dry air and in H_2.—H.W.G.

Carbon Dioxide in Atmospheric Corrosion

A very careful study by Vernon of the factors affecting atmospheric corrosion has produced some interesting results (page MA 316 R 3). In particular, our old enemy, carbon dioxide has turned out to be a friend. In all atmospheres tested, carbon dioxide repressed the rate of corrosion. This is quite at variance with our old ideas of the role of carbon dioxide in the atmospheric class of corrosion—V.V.K.

New Metals for Old

Every metal has particular properties that render it especially useful for certain purposes. The real problem is not the discovery of those properties, but the production of the metal at a cost that will permit the utilization of its particular properties. This requires careful, painstaking research with a dash of imagination thrown in. Notable examples are beryllium and tantalum (page MA 316 R 5).—V.V.K.

More Light on Light

We have known that light had something to do with corrosion. We are glad to see a systematic investigation of its effect (page MA 316 R 6).—V.V.K.

Increase in Rusting Reported

It seems strange indeed that in spite of our widely increased knowledge of causes and prevention of corrosion, rusting of sea-going vessels is, on good authority, on the increase (page MA 316 R 8). As it is ascribed not to poorer quality of the steel but to secondary reasons, continued research into these factors seems imperative and highly interesting.—Ha.

Is Tarnish Resistant Silver About to be Realized?

A recent German investigator has found (page MA 302 R 9) that silver deposited from an iodide solution can, under certain conditions, entrain enough of the iodide anion in the crystalline structure of the cathode deposit to render the silver immune to tarnish by H_2S. While this may not be applicable to Sterling ware, it would seem to have promising possibilities for silver-plated ware. Other striking variations in color and other properties of electrodeposits can be brought about by similar means.—H.S.R.

Only 4 to go to Equal Heinz

Specifications for 53 steels used in the Ford car are listed by *Mill & Factory* (page MA 320 R 2).—H.W.G.

X-Rays, X-Rays

X-rays have furnished plenty of grub for hungry brains this month. Jette and Foote (page MA 311 R 1), for example, turned up some pretty queer things about the iron-nickel system. Owen and Pickup (page MA 311 R 2) re-determined the lattice constants of beryllium. Misch (page MA 311 R 3) X-rayed gold and palladium compounds of beryllium. Other alloy systems worked on were arsenic-lead, by Bauer and Tonn (page MA 311 R 4), lithium-zinc by Zintl and Schneider (page MA 311 R 6) and platinum-thallium by Zintl and Harder (page MA 311 R 9). There must be at least one point of interest in this batch for every reader.—J.S.M.

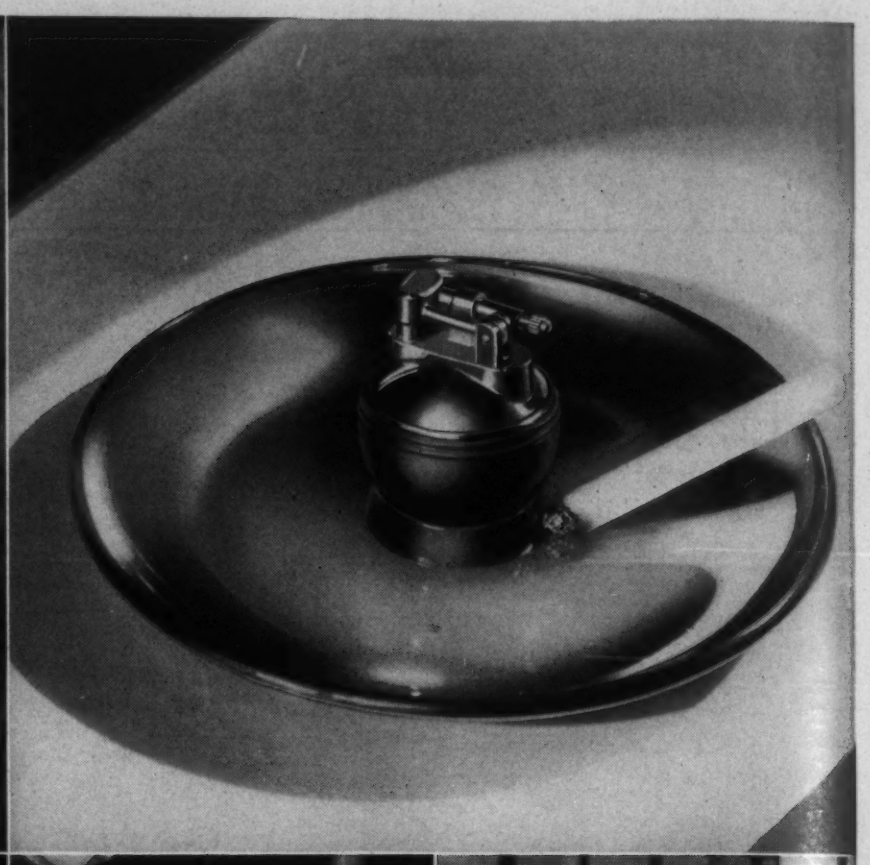
A Rapid Coloring Method for Metals

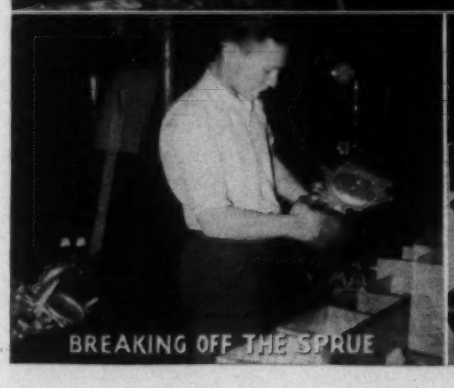
The finish of a metal article is an important matter in many respects and the demand for simple, inexpensive methods for the purpose is an increasing one A solution recently described appears especially useful in that it can be used for copper alloys as well as iron and steel. The solution contains a mixture of sodium thiosulphite, "hypo" to most of us, and lead acetate. An attractive lustrous colored finish ranging from yellow to dark blue can be easily produced (page MA 305 L 8).—H.S.R.

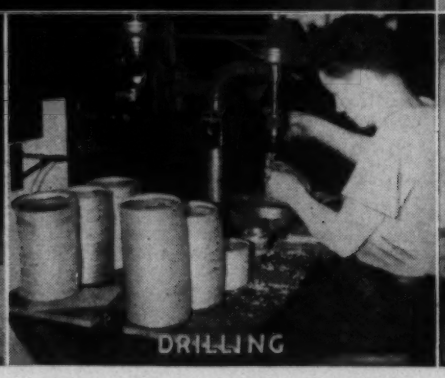
Diffusion

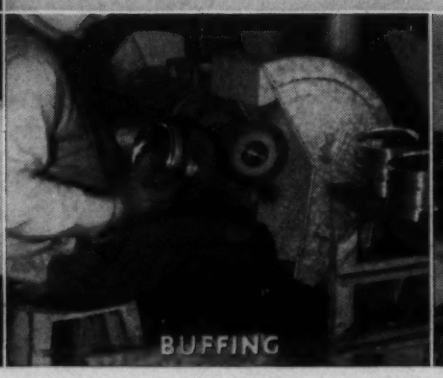
Mayhap Mehl's Institute of Metals Lecture will stir up interest in diffusion in metals where interest was lacking. That metals frequently obey laws that were formulated years ago is being appreciated more widely as suitable experimental data accumulate. The store has been increased this month by data of practical as well as theoretical interest: first, Alty and Clark (page MA 310 R 2) report on the diffusion of Hg on the surface of Sn—the ordinary equations are obeyed; second, Bramley, Haywood, Cooper and Watts (page MA 310 L 3) have plenty to say on diffusion of non-metallic elements (sometimes called "nuisance", but often useful, elements these days).—J.S.M.

HORSE HEAD SPECIAL (99.99+% UNIFORM QUALITY) ZINC









ASH TRAY OR END-PLATE

—make it a ZINC Alloy Die Casting

In considering production methods for your new parts, can you see possibilities from their similarity with other parts? The production pictures shown above are of an ash-tray. Considered more broadly, it's a dish—turned upside down with slight variations it might be a cover, an end-plate or any one of a dozen parts. There were several obvious methods of manufacturing this part; but when costs, ease of finishing and appearance were considered it went to a ZINC Alloy Die Casting.

In our publication, "The Alloy Pot," we try to keep abreast of the rapid developments in this industry. We will gladly place your name on our mailing list to receive the literature on this subject if you so desire.

THE NEW JERSEY ZINC COMPANY

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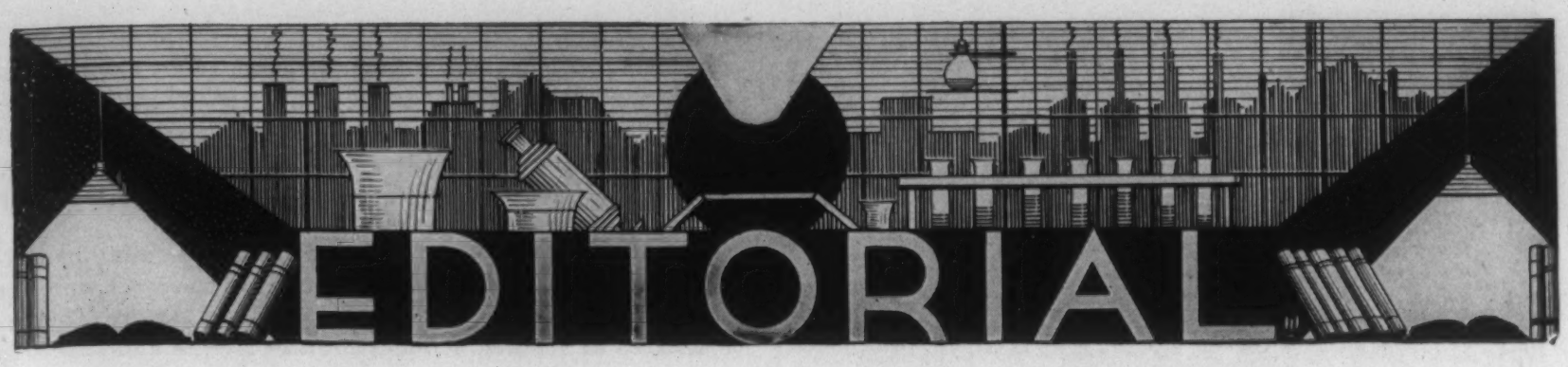

Permanent Set

A RECENT *Readers' Digest* quotes Oliver Wendell Holmes as saying, "Every now and then a man's mind is stretched by a new idea and never shrinks back to its former dimensions."

This is true not only of the individual mind, but of minds in the aggregate as well. The mere fact that someone licks a tough job, makes a casting that others would pass up as impossible to handle, for example, puts that sort of job within the scope of other progressive shops. The way it was done is likely to be described in some technical journal or at some society meeting, but even if it is not, competitors know that the problem is not insoluble and keep after it till they too find out a way.

Insofar as the advances are due to the use of improved equipment, salesmen and advertising join in to spread the news of better ways. But from whatever source the ideas come, it is necessary that there be some means of transferring them from the originator to those who can utilize them. As a recent Bulletin of the Ontario Research Foundation remarked, "Apples form only on trees that are cross-fertilized." Meetings and technical journals are the bees.

But it is also necessary that the bees operate in blossom-time. After one gets too old in mind, for receptivity is not necessarily lost with age, the mind doesn't take a permanent set so readily. The younger generation is usually better able to utilize the new ideas and new facts than the older one.

For this reason, our technical societies should be operated with more of an eye to the youngster than most of them are.

Those in power in any society are the old timers who tend to feel that the society should do things their way and who tacitly assume that everyone else has their own background. Sometimes this results in the papers lacking such prefaces as would make them understandable to the novice, but one of the worst results, to our mind, is the failure to keep entrance fees down and the tendency to make smokers, dinners and so on at the meetings more expensive than the youngster can afford.

When we started to attend technical meetings, and spent our own money to do so, we had to hunt up a cheap boarding house, instead of going to the official hotel, and had to miss the functions where the big guns we wanted to meet, or at least see at close range, would have been more accessible.

We'd like to see some technical society try a sort of Big Brother scheme and hold a session where each of a lot of the old wheel horses took one of the new crop of student or associate members under his wing and saw to it that he met the other oldsters. (Oh yes, horses can have wings; Pegasus did.)

Unless something is done along these lines, some of the societies will not only fail in their main purpose of bringing new ideas and new facts to those who can best utilize them, but will fail to develop enough interest on the part of new comers to perpetuate the society itself after the old-timers pass on.

There are one or two snooty, mutual-admiration, technical societies which pride themselves on their exclusiveness and cater only to the old, established technical man, and which could be dispensed with at no loss, but in general the societies mean all right—they just don't think.

It would be a swell idea for the secretaries of technical societies to drop in at any gun club or skeet club anywhere and note how these sportsmen treat a novice. Nothing pleases a man who has shot all his life better than helping a youngster to learn to shoot. That attitude seems conspicuously lacking in some of the societies.—H. W. G.

Progress in Steel-Making Technique

THAT pronounced progress is being made each year in the solution of open-hearth steel-making problems and in the improvement of the product was the vivid conviction impressed upon those who attended the recent gathering of the Open-hearth Committee of the Mining Engineers held in Detroit. The meeting was the eleventh anniversary of the inauguration of the Committee's work and was signalized by the largest registration thus far.

The free and intimate discussions, on or off the record, and the excellent management guarantee results which are of marked benefit to operating men and to the steel industry. The record of the first 11 yrs. fully justifies and probably exceeds the anticipation of the founders.

In a closely similar field, a younger organization is filling a parallel need. The Electric Metal Melting Association includes in its membership men operating electric furnaces of any type, whether on ferrous or non-ferrous products. This group, however, is closely organized and limited as to its membership, its publicity and in other respects. But the benefits which redound to those allowed to participate doubtless are fully equal to those in the open-hearth group. This organization also meets annually.

Free discussion of current problems in metallurgy is essential to progress in the solution of problems. We have gone a long distance in the more liberal interchange of data since only a few years ago. The large technical societies could take a leaf out of the experience of these furnace groups in the realm of more discussion and less time in the presentation of printed papers. A feature of the open-hearth sessions was the absence of long papers and the extended verbal interchange of opinions.—E. F. C.

Scale-free

CONTINUOUS CLEAN ANNEALING FLYWHEEL RING GEARS IN AN SC GAS-FIRED FURNACE WITH RADIANT HEATING ELEMENTS

● To improve manufacturing methods, one of the largest builders of popularly priced motor cars required equipment for the continuous production at closely regulated temperatures of scale-free annealed fly-wheel ring gears. The installation designed by SC Engineers to meet the rigid requirements of this manufacturer is shown in the illustration.

Gears are conveyed through the furnace on alloy hangers suspended from a continuous counterflow conveyor, entering and being discharged at the same end of the furnace. They are preheated to 500 deg. F. in 30 minutes, heated and soaked at 1500 deg. F. for 36 minutes, and cooled to 700 deg. F. in 60 minutes. Production is 500 gears per hour.

Gas-Fired Radiant Heating Elements located along the side walls, at the rear end wall, and through the center section between and parallel to the conveyor lines, assure positive temperature control in every section of the heating chamber, and work free from oxide scale.

After annealing, the gears pass through a coining operation; the teeth are cut, and then they are hardened in an SC Controlled Atmosphere Clean Hardening Furnace.

The rigid requirements of the manufacturer are successfully and satisfactorily met by this installation.

Whatever your heat treating needs may be SC Engineers will be glad to discuss them with you.

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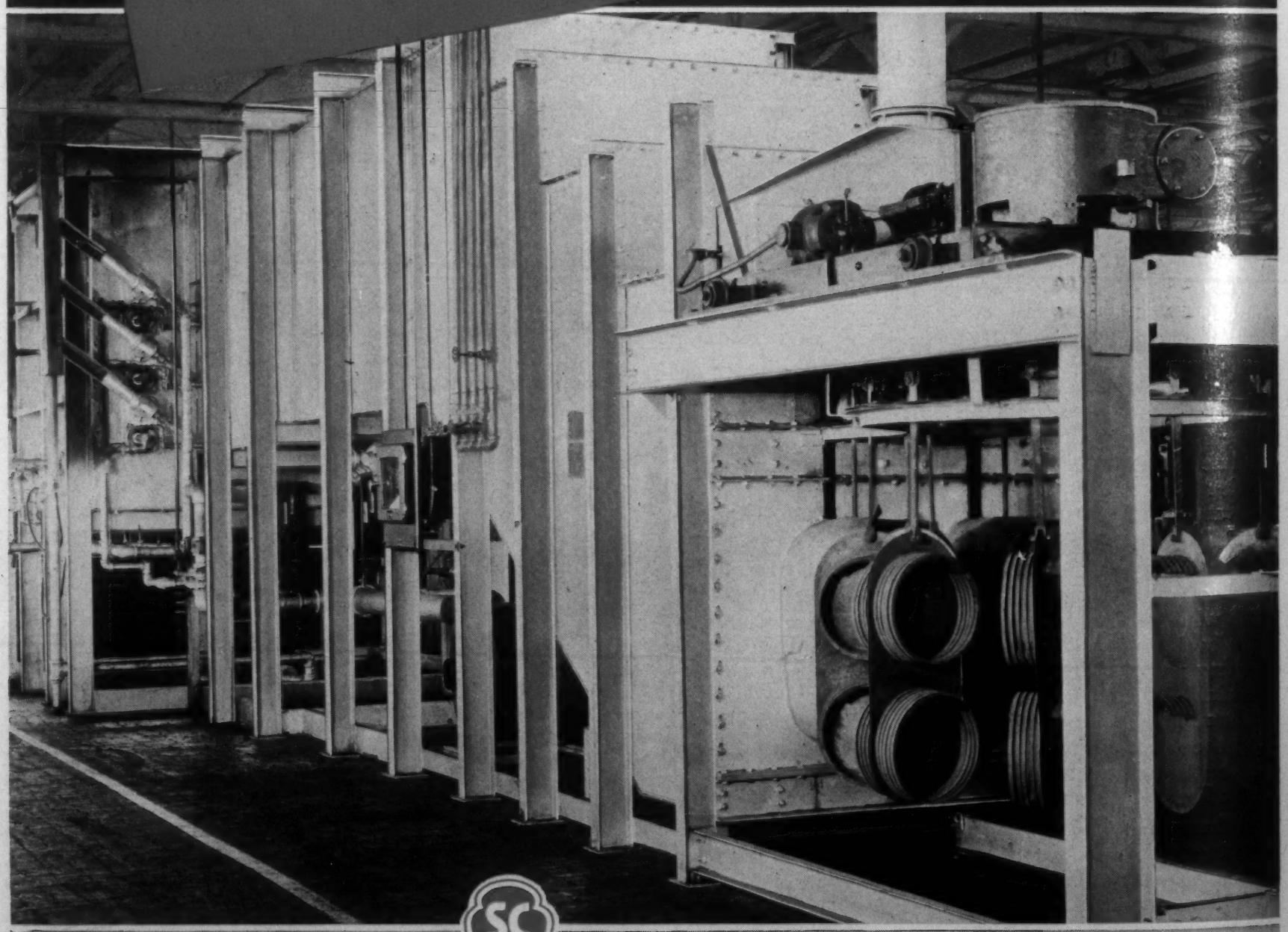

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NEW ELECTRIC PROCESS
for
Cyanide and Activated Baths

By E. F. DAVIS

Chief Metallurgist, Warner Gear Co., Muncie, Ind.

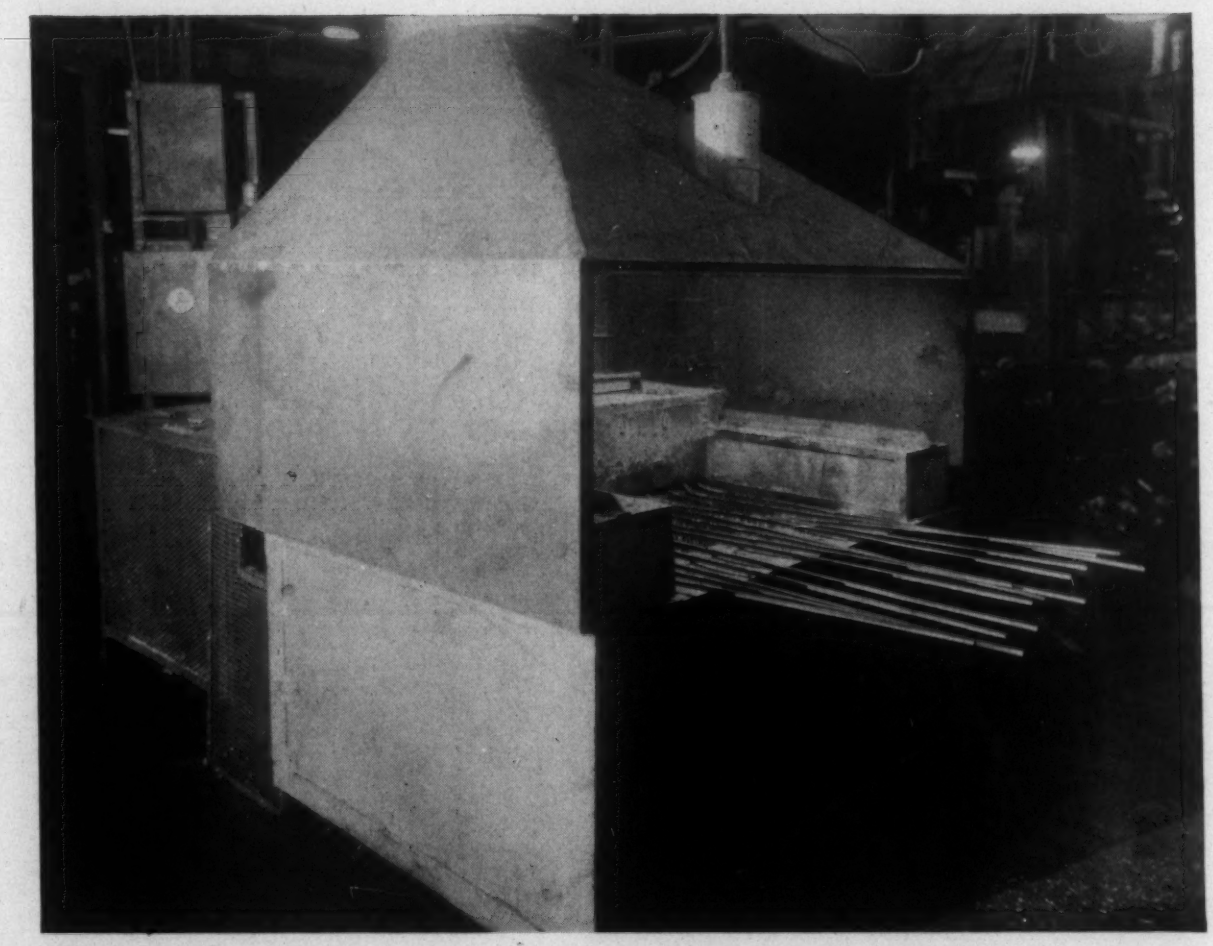


Fig. 1. The Hooded Ajax-Hultgren Furnace with a Production Heat in Process.

NEARLY ALL PRODUCTION hardening by immersion processes is now being done in gas or oil-fired furnaces using either round, square or rectangular pots set into a fire brick combustion chamber. Several types of externally heated electric furnaces were in vogue a number of years ago, but their expense of upkeep and maintenance and high fuel costs caused them to lose popularity and such furnaces are obsolete in the larger industries. Other types of electric furnaces are employed extensively in tool hardening but several features of their construction make them impractical or uneconomical for production heat treating.

Some Preliminary Remarks

In the common designs the pots employed in immersion hardening are heated by the combustion of fuel in a combustion chamber. The heat absorbed by the pot walls is communicated to the salt in the pot and sufficient temperature must be supplied to hold it in a state of fusion at any desired temperature. This molten fluid by contact with the metal immersed therein imparts its heat to the steel. Such a method is obviously wasteful and inefficient, and this condition has long been realized by metallurgists and furnace engineers but no more practical way of doing this has been available.

In these furnaces the combustion chamber must be held at about 300 deg. F. higher than the desired operating temperature of the molten salts. Thus, if a hardening temperature of 1500 deg. F. is desired for production hardening, the combustion temperature would be approximately 1800 deg. F. This is necessary so that the pots may recover their temperature quickly from the chilling effect on the salt caused by placing cold metal into the bath. If this thermal differential were not maintained, furnaces would heat up too slowly and heat-treating cycles would be much prolonged.

Most immersion pots are made of cast steel and the high temperatures and combustion gases have a destructive effect upon the outside of the casting exposed to the burning fuel and the rate of oxidation is very rapid. A pot life of 1000 to 1500 heat hours, which is equivalent to 6 weeks to 2 months production operation, is considered good performance for such con-

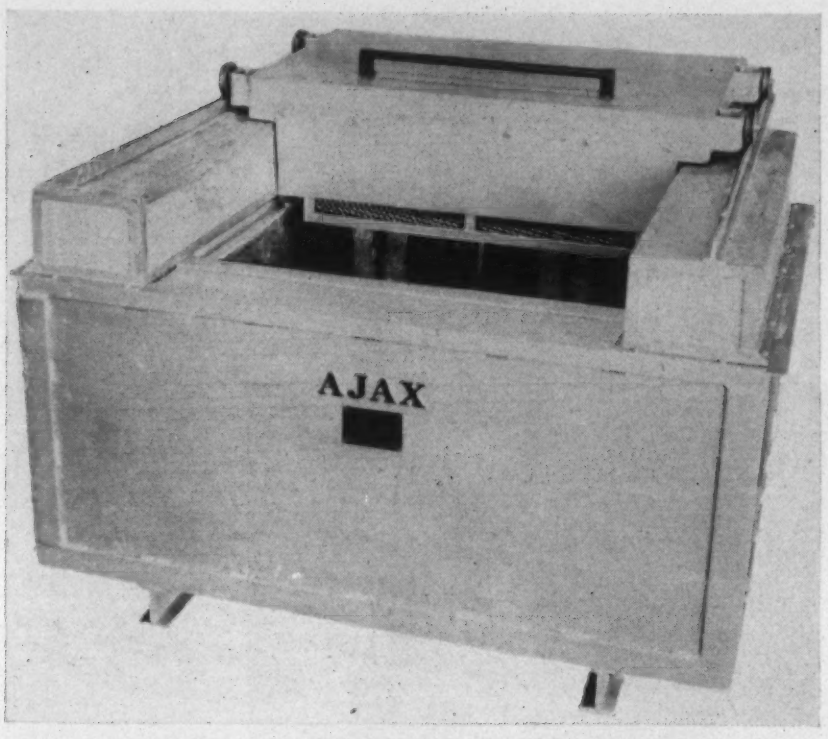


Fig. 2. Position of the Units in the Furnace and the Rolling Cover.

tainers. If heat-resisting alloy is employed, the effect of oxygen and sulphur is of course diminished as far as oxidation and gas corrosion is concerned, but certain internal changes take place in the structure of the metal or porous spots develop leaks, due to the solvent effect of cyanide on the oxides in the porous area, so that the life of such pots is a hazardous gamble. The same is true, of course, with cast steel containers but the alloy pots are more difficult to cast solid. An alloy pot may last two months to two years but the high initial cost causes the average hardening department to prefer the low priced cast steel container.

Description of the New Furnace

These preliminary remarks are given to convey the advantages we have found in a new development by the Ajax Electric Co. of Philadelphia, known as the Ajax-Hultgren salt bath furnace, whereby the salt is heated by its own resistance between electrodes within the bath and the pot is set into insulating fire brick so that all the heat generated by the current passing between the electrodes is transferred directly to the molten bath and the wastage of fuel and destruction of pots is largely eliminated. While this is not the first time interior heating by electric units has been attempted and several methods have been described by Stansel,[1] Russ[2] and Paschkis[3] yet the Ajax-Hultgren Furnace appears to be the most practical one offered for production salt bath hardening.

The first production furnace installed in the United States was put into service at our plant, the Warner Gear Co., Muncie, Ind., Jan. 5, 1936. This furnace is simple in construction consisting essentially of a pot and two pair of electrodes, each pair serving as a heating unit and generating heat by virtue of the resistance of the fused salts in the space between each electrode. A small transformer at the rear of the furnace, an immersed thermocouple in the bath, and the usual automatic control apparatus complete the necessary equipment. A step-down transformer is required owing to the low resistance of the molten salt. The rating is 50 k.v.a.

The overall dimensions of the furnace are 57 by 46 by 27 in. high. The pot is made of welded plate, rectangular in shape, and measuring 37 by 27 by 20 in. deep. The furnace rests on skids so that it may be easily lifted by an elevating truck and moved to any location desired. Over the pot is a rolling cover which may be pushed out of the way when the furnace is being charged or the parts quenched. Figs. 1 and 2 are illustrations of this furnace. Fig. 1 shows the position of the units and the rolling cover; Fig. 2 is the hooded furnace with a production heat in process.

The electrodes are made of heat resisting alloy of suitable composition to maintain the correct potential and to prevent the heat from traveling back to the connections of the electrodes to the transformer. Each pair of electrodes is closely spaced from each other and this distance may be adjusted as desired. The electrodes are located on the same side of the bath so that the working space is kept distinct from the heating zone. An alternating current is employed to prevent the electrolysis or decomposition of the salt which characterizes direct current heating. Fig. 3 shows a diagrammatic sketch of the principles involved.

When the current is started, enough resistance is developed between the electrodes to fuse the salts between them. By feeding more salt in the space between the electrodes, a gradually increasing pool of molten salt is formed which continues to enlarge by the flow of fused material until finally the entire contents of the pot are melted. This particular pot holds 750 to 860 lbs. of material depending upon whether cyanide or chlorides constitute the bath. The chlorides, being of greater specific gravity, would of course require more weight of salt. The same would be true in regard to the purity of the cyanide. The more impure

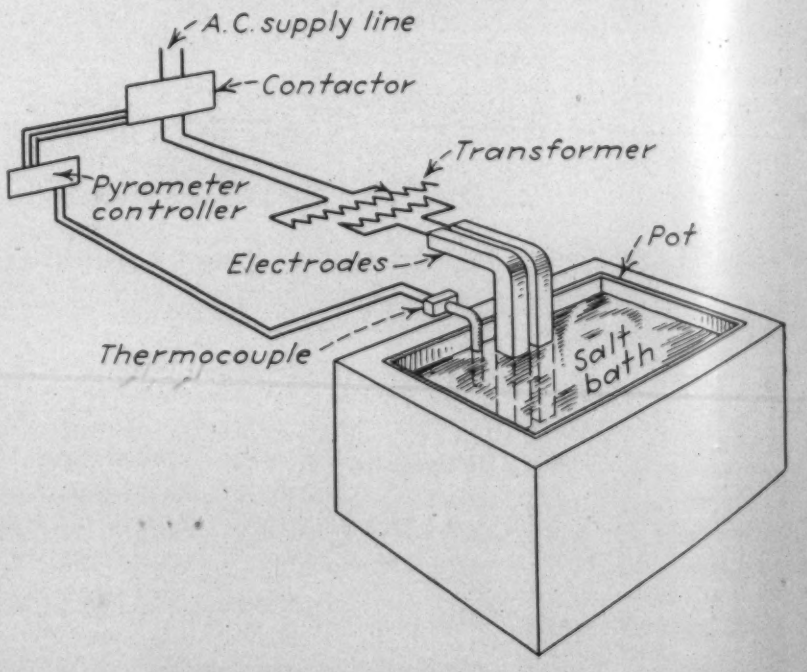


Fig. 3. A Diagrammatic Sketch of the Principles Involved in the New Furnace.

grades and the cyanide chlorides would be heavier than the 96 to 98 per cent grades.

The time necessary to bring a cold pot up to an operating temperature of 1530 deg. F. was 6 hrs., which is equal to the time required by a gas furnace of the same size and capacity. Fortunately we had gas-fired furnaces of the same size for comparison. The

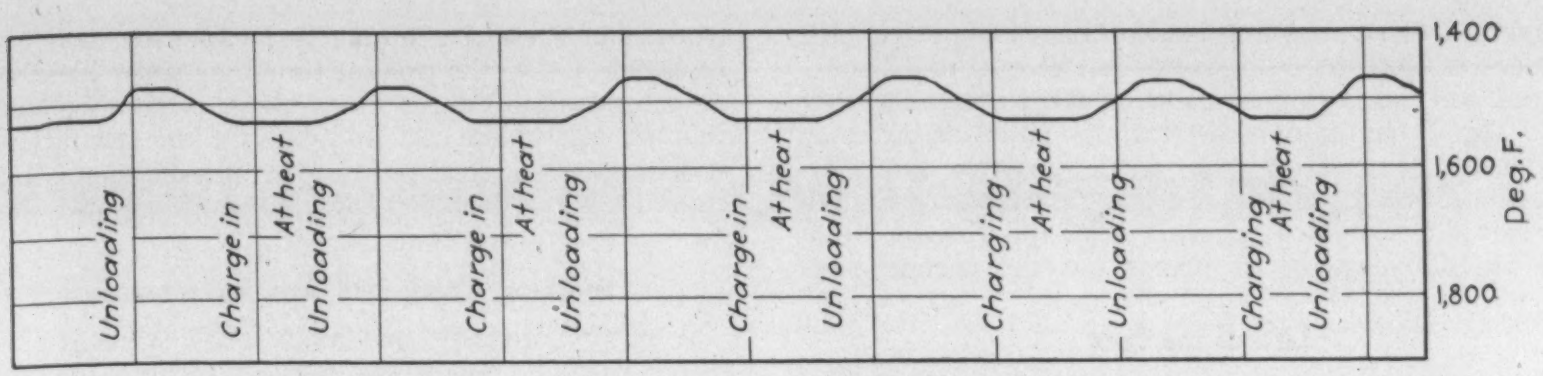


Fig. 4. Leeds and Northrup Chart Showing Temperature Control of Ajax-Hultgren Salt Bath Furnace under Production Operation. Heat treating cycle, 45 min. Temperature, 1530 deg. F. Low points in curve represent quneching and loading period. Note rapid recovery of temperature after loading and extreme uniformity at hardening temperature (straight line section of curve).

current consumed during this period was 240 kw. hr. which, at 1c per kilowatt hour gave us an initial cost of $2.40 to bring the bath from initial fusion to working temperature.

Automatic Stirring a Feature

A peculiar phenomenon occurs in the movement of the fluid whereby the molten salts are drawn between the electrodes and downward to produce a continual automatic stirring of the bath, which uniformly distributes the heat generated between the electrodes. This positive circulation is the result of the specialized electrode arrangement which utilizes the electro-magnetic forces created at the electrodes. Consequently there is no local overheating and no excessive decomposition of salt occurs at the electrodes, indicating that the heat is carried away as fast as it is generated. Fig. 7 shows the check results obtained in various parts of the furnace compared with the furnace thermocouple. A maximum variation of 5 deg. was found.

This furnace was designed for a capacity of 350 lbs. per hr., but, due to production necessity, only parts of bulky character have been hardened to date as shown in Fig. 6. Hence all furnace data, including the thermal efficiency, are based upon hardening conditions which are far from ideal and do not represent the maximum economy of the furnace. The total weight per heat is 103 lbs. and the hardening cycle 45 min. and each piece must be individually quenched. The current consumption over a number of heats showed an average of 26.5 kw. hr. At 1c per kilowatt hour the cost to heat treat 137 lbs. per hr. is 26.5c. This cost compares favorably with most gas or oil-fired furnaces based on 4 cu. ft. of 1100 B.t.u. natural gas per pound of steel treated.

Based upon the above production operations, the thermal efficiency of this furnace is 39 per cent. Increasing the poundage per heat to the furnace capacity would no doubt increase this efficiency materially because the radiation losses are more or less constant and, after the equilibrium was reached, the only additional current consumed would be that required to heat the steel.

It is of course inadvisable to permit the salt to freeze in the furnace during short intervals of idleness, due to the expense and loss of time to bring the furnace up to heat again. It was decided therefore to hold the furnace at 1200 deg. F. or just above the freezing point of the salt over the week end and at other periods when the bath was not in use. As an example of the low radiation losses, it required 6 hrs. for the furnace to drop from 1530 to 1200 deg. F. To maintain it at this stand-by temperature beyond this first 6 hrs. required 6.5 kw. hr. per hr. or a cost of 6½c per hr. To bring it back to 1530 deg. F. required an average of 80 min. and a current consumption of 48 kw. hr. and cost 48c. The preceding is an average of several weeks' checking of power consumption. The quick recovery of temperature is due of course to the direct generation of heat within the bath and the insulation surrounding the pot which reduces the heat losses.

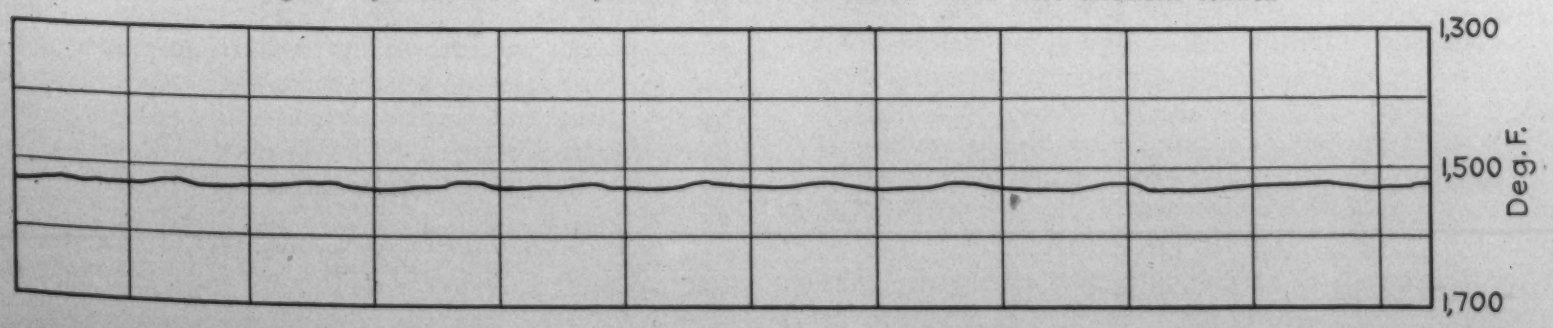
Due to the low voltage employed by means of the transformer, there is no danger of the furnace operator receiving any sensible shock from the current. On several occasions the work being hardened has accidentally touched the electrodes and the work was fused where the arcing occurred but at no time was there any realization of this by the workman. There is considerable magnetic attraction for the steel by the electrodes when the cold metal is first placed in the bath but this disappears after the steel is heated.

Uniformity of Hardness

It has been noted that the product hardened in this furnace is much more uniform in hardness than the same work from the gas-fired salt bath furnaces both of which were in operation on the same parts. One reason for this is that the temperature can be held much more uniformly than is possible in the gas-fired furnaces for the latter will always float over or under the desired temperature in spite of the best automatic control. In the Ajax-Hultgren furnace production heats are run all day and night without a variation in temperature in excess of 5 deg. F.

Fig. 4 shows a typical production chart from a Leeds and Northrup record on the electric furnace. The dip in the curve is the period of unloading and loading the pot, for these are placed in the furnace one at a time and individually quenched. The quick recovery of

Fig. 5. Ajax Furnace at Temperature with No Production. Note close automatic control.



temperature after loading is also illustrated. After the furnace is charged with work, between 10 to 12 min. is the total time required to bring the furnace back to 1530 deg. F. In many heat-treating operations the time cycle could be materially shortened, due to the ability of the electrodes to supply the heat as needed. Fig. 5 illustrates a section of a chart with the furnace held idle at 1430 deg. F. It brings out the accuracy of control.

Life of the Pots

One of the outstanding economies of this furnace is extended pot life. The pot material is merely welded

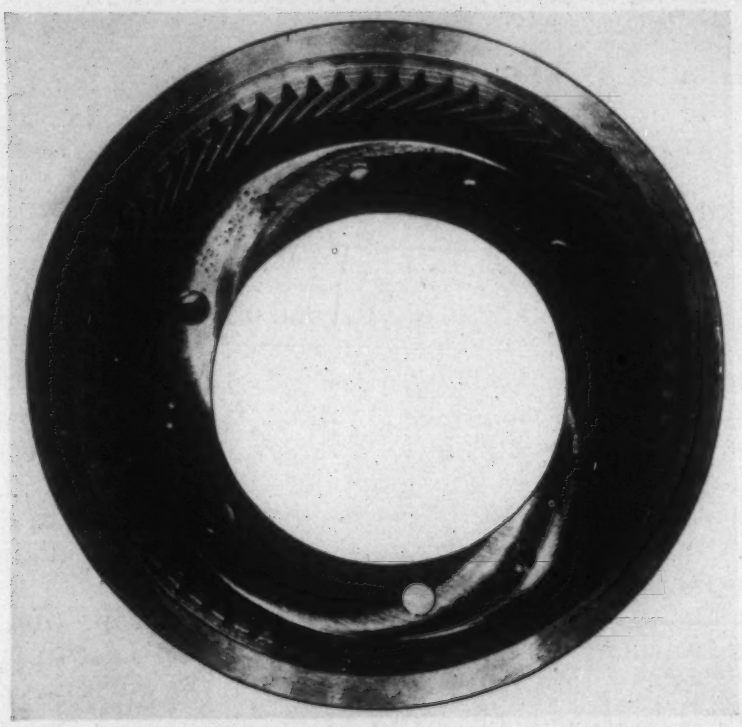


Fig. 6. Parts Now Being Hardened in an Ajax-Hultgren Furnace.

steel plate imbedded into the insulating fire brick. All scaling and corrosion incident to exterior heating and the high temperature of the combustion furnace, is eliminated. The outer surface of the pot, being protected by the brickwork, is under no strain from the contents and can therefore be made of light metal. Neither the salts used in the cyanided or activated baths have any corrosive effects on steel, the only action being one of gradual carburization and some crystalline growth due to prolonged heating. Instead of an average of 6 weeks to 2 months pot life this spot has, to date, given 5 months' service and a recent examination showed no visible deterioration. It is yet a little early to determine just how long these pots will last but we estimate at least a year's service.

The cast steel pots used in the gas-fired furnace of the same size cost about $45 and weigh over 500 lbs. When a pot fails in these furnaces nearly 24 hrs. loss of production is experienced. The pot must be shut down, the cyanide or other salt ladled out, the furnace allowed to cool and, as soon as the pot can be handled, it is removed. Owing to the destructive action of the salt leaking into the combustion chamber, the surface of the brick must be relined with fire clay. A new pot is then installed, the salt remelted and the furnace again brought to temperature. Such a change costs about $20 or a total of $65 including the new pot. This procedure must be repeated every 6 weeks to 2 months. If one year of pot life is obtained, an obvious saving of $400 to $500 in maintenance cost would result which would easily pay the fuel cost for heat treating 100 tons of steel in the Ajax-Hultgren furnace.

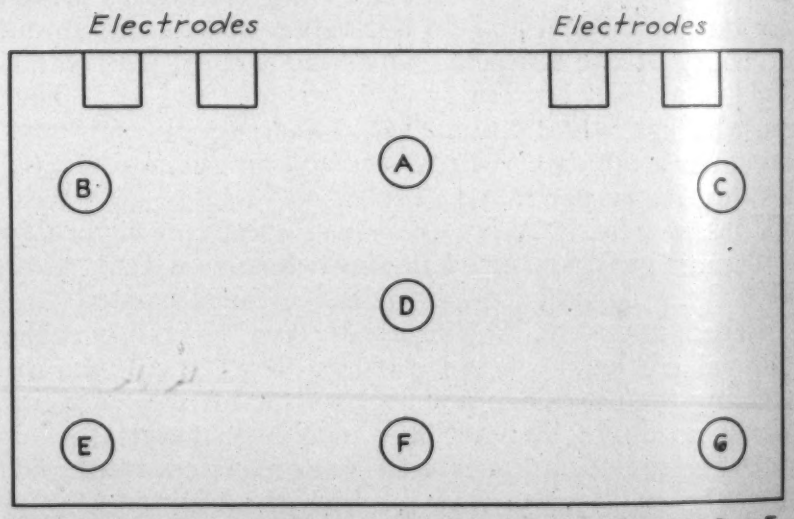
It is a little early to determine the life of the electrodes but these are relatively inexpensive and easily replaced. Up to the present time they show little signs of deterioration except where there was an accumulation of salt above the molten salt line permitting a short across the electrodes. This was due to failure to clean the space between each pair and was not due to corrosive action within the bath.

Working Conditions Are Advantageous

Another noticeable and important advantage is the better working conditions for the furnace operators. There is very little radiant heat. Cyaniding is one of the most unpleasant of all the heat-treating operations and anything which adds to the comfort of workmen is advantageous from a standpoint of health and labor turn-over.

A certain amount of fume always attends salt bath hardening, due to vaporization and quenching. Scrubbers to wash out these fumes will usually take care of the vapors from normal operations. The fumes which are really objectionable are those copious fumes which are caused by a leaking pot which allows the salt to drop into the hot combustion chamber of the gas or oil-fired furnace. I have never seen a scrubber which would efficiently remove the great clouds of vapor from the volatilized salts. When plants are located in residential neighborhoods, as they often are, this has been a source of annoyance and many claim it is destructive to paint films and vegetation. With the Ajax-Hultgren furnace this condition cannot occur.

It would be far-fetched to claim that this furnace is a panacea for defective hardening or that the work so treated is superior to the quality of product from gas or oil-fired furnaces. Furthermore there are many other factors, other than the means of applying heat, which enter into metallurgical processes. However, many of the variables occurring in production hardening can be treated to the lack of close temperature control and the human element, and anything which minimizes the chance for error whether it be



A- Furnace Couple 1560 Deg.F. D-Check Couple 1560 Deg.F.
B- Check Couple 1560 Deg.F. E-Check Couple 1555 Deg.F.
C- Check Couple 1560 Deg.F F-Check Couple 1560 Deg.F.
G- Check Couple 1555 Deg.F.

Fig. 7. Pyrometer Readings on Ajax-Hultgren Salt Bath Furnace in Various Portions of Bath Operating at 1560 Deg. F.

mechanical or metallurgical is advantageous in eliminating trouble and improving production quality and we believe this furnace is an advanced step in salt bath heat treating and will be welcomed by industries doing this class of work.

References

[1] N. R. Stansel. Industrial Electric Heating, 1933, page 87.
[2] F. Russ. Die elektrische Warbehandlung, 1933, pages 218-219.
[3] V. Paschkis. Elektrische Industrieofen für Weiterverarbeitung, 1932, pages 278-281.

Nickel Steels at Low Temperatures—I

An Investigation of the Impact Properties of the 2¼ Per Cent Steels

By B. G. ALDRIDGE AND GEORGE C. SHEPHERD, JR.

Development and Research Departments, Respectively, of the Union Oil Co. of California.

SINCE 2 to 2.50 Ni steel is a thoroughly proven material for low temperature use, this correlation of impact figures secured with various notches and specimen dimensions on several lots of such steel is very useful when that particular type of steel is under test. The reader should, however, be cautioned not to assume that similar correlation factors would necessarily hold for any other type of steel. Indeed, it would be most surprising if these particular factors would hold for those steels that, at some temperature range, do shift abruptly from a curve of high values to one of low values. In such a case one notch or one bar size might show acceptable values, while another notch or size, instead of being related by a factor predictable from these data for another class of steel, might drop to entirely unacceptable values—a matter to be found out only by tests on a range of notches and sizes.

It is to be hoped that similar correlation tests will be carried out on a wide variety of steels so that those classes for which definite correlation factors exist, and the actual factors, may be established as the authors have established them for this one type of steel.—H. W. G.

IN THE EARLY PART of 1933 the Union Oil Co. of California, after several years of research work directed toward the manufacture of paraffinic lubricating oils from mixed base crude oils, decided to install a propane solvent plant for the dewaxing of lubricating oils from California crude oils.

In the design of a commercial plant the engineers were immediately confronted with the problem of what effect the low temperatures involved would have on the impact strength of the steels used in the manufacture of the necessary pressure vessels, pumps, piping, valves, etc. The propane process ordinarily operates at temperatures varying from one hundred degrees Fahr. (100 deg. F.) to temperatures as low as minus forty-five degrees Fahr. (—45 deg. F.), and in cases of upsets in the operation, temperatures as low as minus seventy-five degrees are sometimes reached.

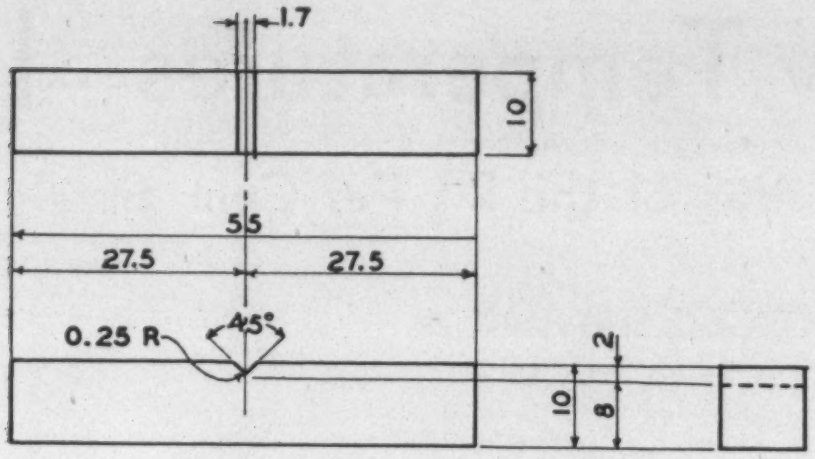
In the studies of the literature on the subject of impact properties of steels at low temperatures, it was found that the available data were rather meager, and in many instances, conflicting and confusing. In general, the data covered small specimens of steel that could be readily subjected to any heat treatment desired. The most usual treatment consisted of heating the steel to a temperature above its thermal critical point and quenching in oil or water, with a subsequent drawing at temperatures below the critical. There are a relatively large number of steels that will give satisfactory impact values at low temperatures when subjected to the above heat treatment, but since some of the vessels required in the plant would weigh as much as 50 tons each, it was evident at the start that it would be impracticable to use any type of treatment that would require a sudden quenching of the steel. It was, therefore, necessary to find a steel that could, in the form of rather large and heavy rolled plate or castings, be successfully heat treated and at the same time not be prohibitive from the standpoint of cost. After preliminary tests on the most promising of the medium priced commercial steel alloys, a nickel steel with approximately a 2.25 per cent nickel content was selected, since it was felt that it would present the least fabrication difficulties and the cost of the steel was not out of line.

Method of Making Impact Tests

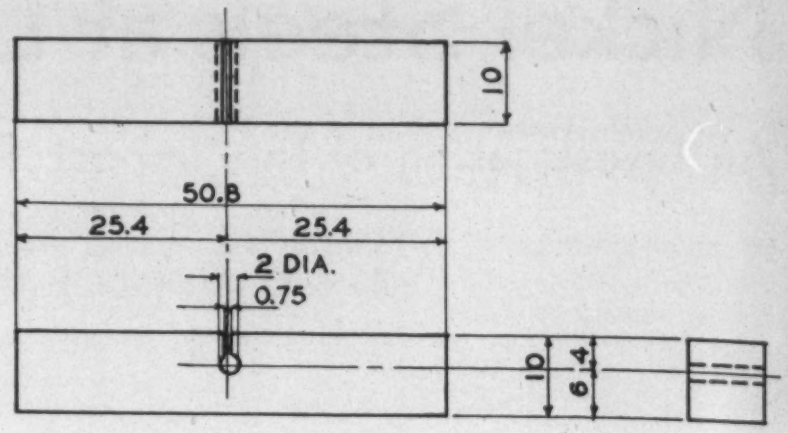
When testing the steel for its impact properties at low temperatures, the general procedure was as follows:

> The impact specimens, other than those tested at a temperature of plus seventy degrees Fahr. (+ 70 deg. F.), were cooled in an acetone bath and the desired temperature was maintained manually by the addition of small lumps of carbon dioxide ice as needed. All specimens were subcooled to a temperature of three degrees Fahr. (3 deg. F.) below the desired testing temperature to compensate for any warming up of the specimens during the approximate four second interval between removal of the specimen from the cooling bath and the moment of test. The handling tongs and the clamping mechanisms were also pre-cooled to the same temperature as the specimens. Calibrated toluene thermometers were used for the —50 deg. F. and —75 deg. F. tests, and an accurate mercury thermometer for the 0 deg. F and 70 deg. F. tests.

The major portion of the impact tests was made on a standard Charpy 217 ft-lb. machine which was calibrated to an angle of rise corresponding to approximately 0.1 ft.-lb. In some cases, however, we were forced to employ an Izod type impact machine, which made it necessary to reduce the test results to some common basis. Correlation of the test results was further complicated by the fact that, due to thickness of some of the material used in the manufacture



Detail A



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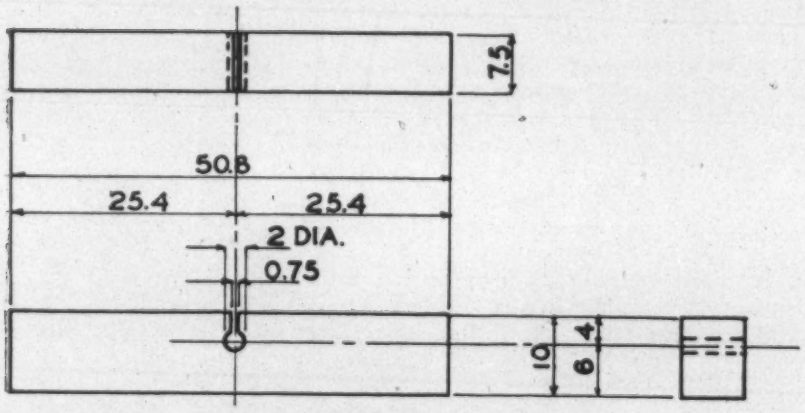

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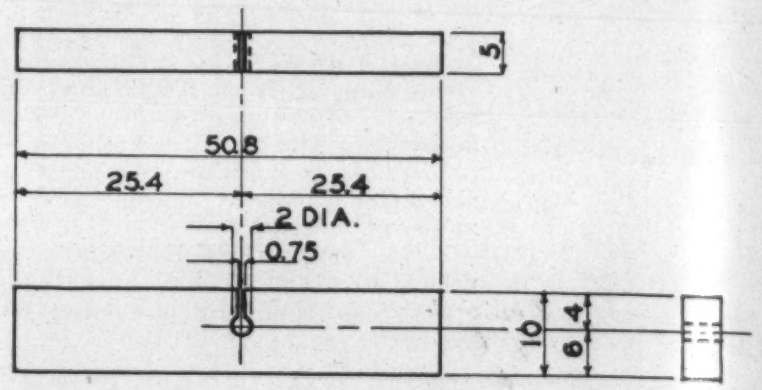

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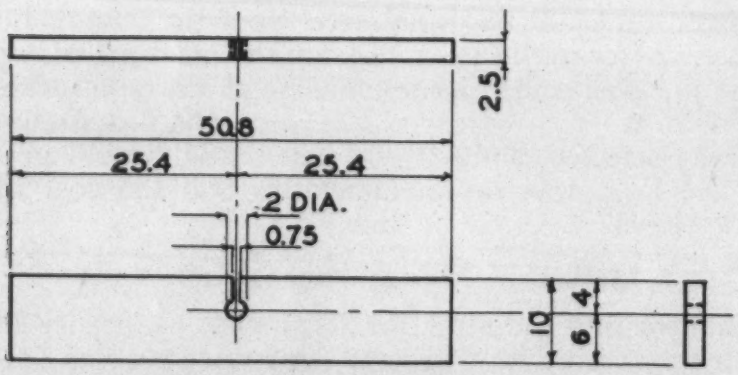

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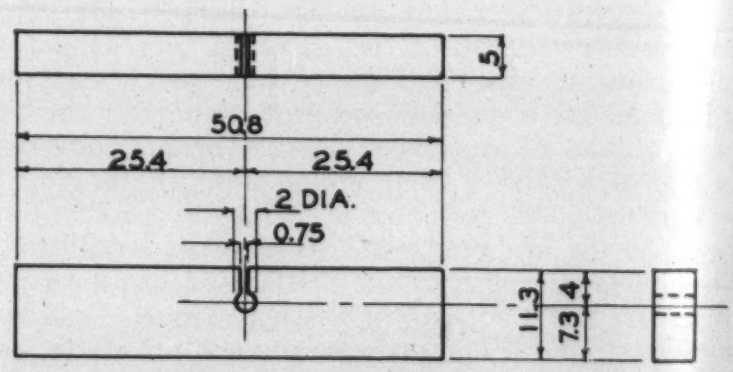

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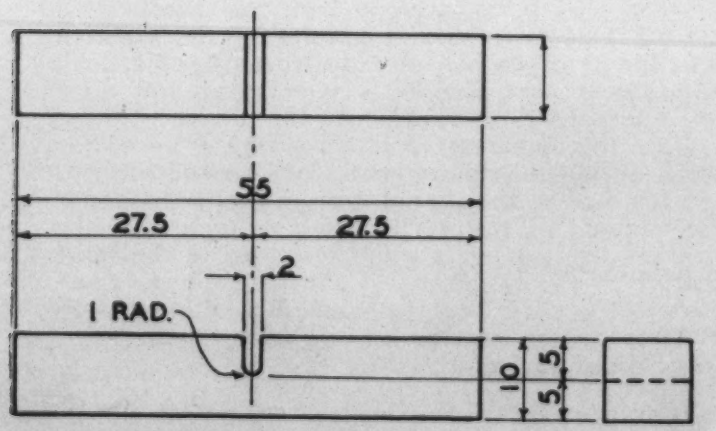
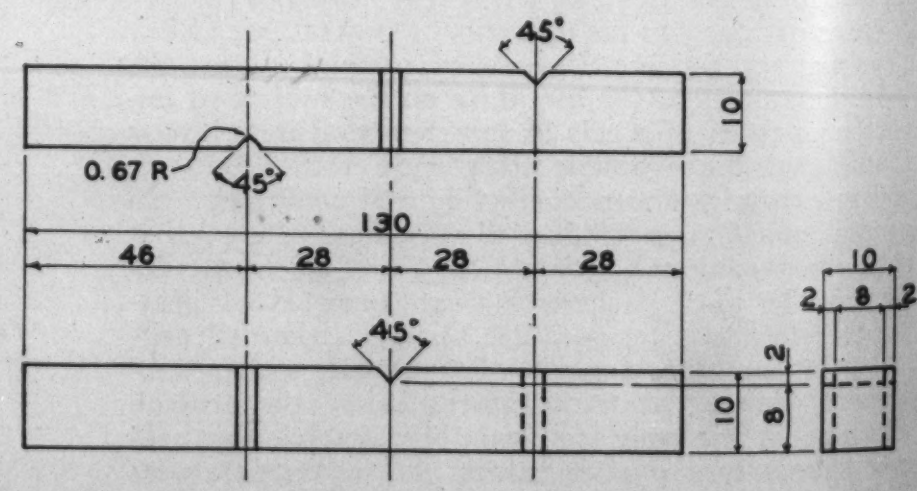


Detail G



Detail H

ALL DIMENSIONS IN MILLIMETERS

Fig. 1. Details of Impact Specimens.

of equipment, it was not always possible to secure a test specimen of standard dimensions.

As a means of correlating the impact values obtained by the different laboratories concerned with our work on the impact properties of various metals at low temperatures, we submitted specimens to these laboratories for impact testing. The specimens selected were taken from two separate nickel steel plates, and impact tests in duplicate were made by the laboratories on specimens from each of these plates.

Table 1.—Comparison of Impact Test Values Obtained by Various Laboratories

Plate	Relationship of Major Axis of Specimen to Direction of Rolling	Relationship of Axis to Keyhole Notch to Plane of Rolling	Temp. of Test, Deg. F.	Charpy Impact Value, ft.-lbs.				
				Laboratory I	Laboratory II	Laboratory III	Laboratory IV	Aver.
1	Longitudinal	Parallel	70	44.7	44.4	...	38.2	42.4
1	Longitudinal	Perpendicular	70	46.6	39.6	...	38.2	41.5
1	Transverse	Parallel	70	32.6	31.5	...	27.0	30.3
1	Transverse	Perpendicular	70	28.5	27.6	...	28.2	28.1
1	Longitudinal	Parallel	—50	44.2	32.8	...	31.5	36.2
1	Longitudinal	Perpendicular	—50	36.6	34.2	...	31.5	34.1
1	Transverse	Parallel	—50	26.0	22.5	...	22.5	23.7
1	Transverse	Perpendicular	—50	25.0	22.4	...	23.8	23.7
2	Longitudinal	Parallel	70	44.3	43.2	42.0	43.0	43.1
2	Longitudinal	Perpendicular	70	45.9	44.4	43.5	43.0	44.2
2	Transverse	Parallel	70	37.6	39.3	35.0	34.0	36.5
2	Transverse	Perpendicular	70	35.0	34.1	36.5	31.5	34.2
2	Longitudinal	Parallel	—50	31.5	29.2	28.5	26.0	28.8
2	Longitudinal	Perpendicular	—50	30.6	29.0	25.2	28.5	28.3
2	Transverse	Parallel	—50	24.4	23.5	22.5	21.0	22.8
2	Transverse	Perpendicular	—50	23.7	21.8	22.5	23.8	23.0
1	.....	.....	70	38.1	35.8	...	32.9	35.6
1	.....	.....	—50	33.0	28.0	...	27.3	29.4
2	.....	.....	70	40.8	40.2	39.3	37.8	39.5
2	.....	.....	—50	27.6	25.8	24.6	24.8	25.7

Plate No. 1 was a ½-in. thick rolled nickel steel plate which showed the following chemical compositions:

	Per Cent
Carbon	0.13
Manganese	0.46
Nickel	2.11

The only heat treatment given this plate was a draw at 1150 deg. F.

Plate No. 2 was a 1⅜-in. rolled, 2.25 per cent nickel steel plate which showed the following chemical composition:

	Per Cent
Carbon	0.27
Manganese	0.66
Nickel	2.41

This plate was normalized at 1450 deg. F. for 1 hr., and then drawn at 1200 deg. F. for 1 hr. Each of the laboratories machined standard American Society for Steel Treating (now Amer. Soc. for Metals) Charpy impact specimens from the plates and notched them to conform to the ASST recommended, or as we shall term it for brevity, "standard" keyhole notch. In notching these specimens, particular care was taken by all the laboratories to insure that the standard ASST distance from the bottom of the notch to the bottom of the specimen was correct. The results of these correlation tests are shown in Table 1.

The tests show that the impact values obtained by Laboratory I are, in general, 2 to 4 ft.-lbs. higher than those obtained by Laboratory II, and that the values obtained by Laboratories III and IV are very similar and are, in general, 1 to 2 ft.-lbs. lower than those obtained in Laboratory II.

The mechanics and technic of American Society for Testing Materials Tentative Standard E23, "Tentative Methods of Impact Testing of Metallic Materials," are quite similar, with the exception of the impact specimen, to that employed by the various laboratories which we contacted. The ASTM Charpy specimen is shown in detail A, Fig. 1, and the ASST Charpy specimen is shown in detail B also of Fig. 1.

It will be noted that the ASTM specimen is slightly longer than the ASST specimen (55 mm. as compared to 50.8 mm.), but, as the jaws of the anvil for both specimens are separated by a width of 40 mm., this is believed to be of only minor import. The major difference lies in the method of notching and the amount of metallic area to be broken on impact. The ASTM and ASST standard specimens both have, in the unnotched condition, a cross section of 10 mm. by 10 mm. The notch in the ASTM specimen has a shallow "V" outline and the notch has a radius of 0.25 mm. at its base. The notch in the ASST specimen has a keyhole outline and the notch has a radius of 1.00 mm. at its base. The notch in the ASTM specimen presumably would be made with a milling cutter, whereas the notch in the ASST specimen is made with a drill followed by a saw cut. The base of the notch in the case of the ASTM specimen is, therefore, more apt to have striations longitudinal with the notch than is the base of the ASST specimen notch, where such striations would be presumably helical. In the case of the milled 0.25 mm. radius notch of the ASTM specimen, it is believed that this notch is more likely to have a higher variation in its radius, due to differences and wear in the milling cutters, than is the ASST notch which is drilled with a 2-mm. drill. As will be shown later, the radius of the notch has an appreciable influence on the impact value obtained, and the smaller the radius the greater the possibility of error in the impact value which will be induced by errors in the radius of the notch.

The ASTM specimen has a breadth of metal under the notch of 10 mm. and a depth of metal under the notch of 8 mm. The ASST specimen has a breadth of metal under the notch of 5 mm. The ASTM specimen, therefore, has an area to be broken under the notch of 80 sq. mm., whereas the ASST specimen has an area of 50 sq. mm., a ratio of 1.60 to 1.00. If we compare the moments of inertia of the metallic area under the notch on the basis of the BD^3 (breadth times depth cubed) of the area, we find that the ASTM specimen has a BD^3 of 5120, whereas the ASST specimen has a BD^3 of 1250, a ratio of 4.10 to 1.00. Table 2 shows the results of correlation tests made with the two types of specimens and Fig. 2 portrays this correlation graphically.

Undoubtedly, the ASTM notch (0.25 mm. radius) will cause much greater intensification of stress at the notch, due to its sharper radius, than will the ASST notch (1.00 mm. radius). On the other hand, the ASTM specimen will tend to absorb more energy

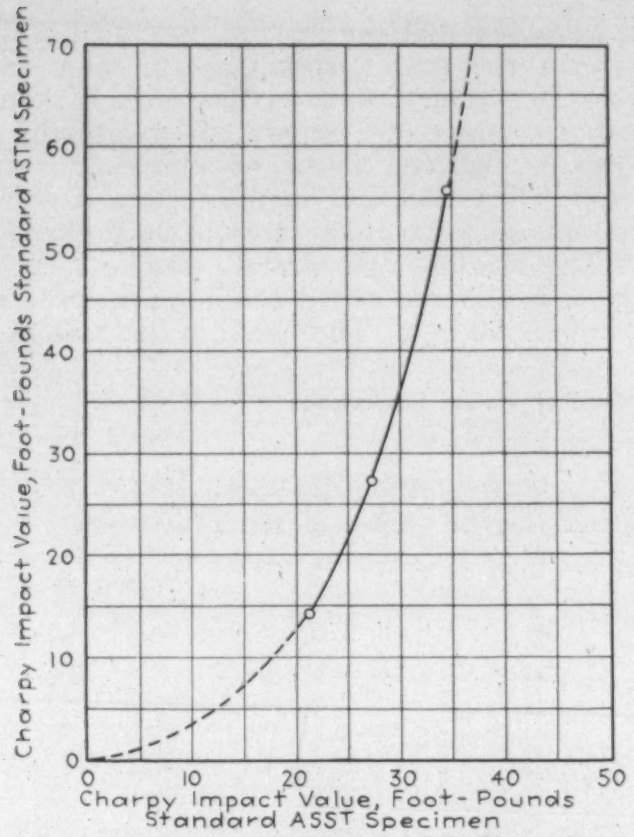


Fig. 2. Relationship Between Standard A.S.S.T. Charpy Impact Specimens (Keyhole Notch) and Standard A.S.T.M. Charpy Impact Specimens (Shallow "V" Notch).

in rupture than will the ASST specimen, due to its 60 per cent greater area to be broken and its approximately four times as great moment of inertia. On the basis of the foregoing and the impact results obtained in this series, we can draw the conclusions that the influence of the notch is much more pronounced than the influence of areas, or moment of inertia in materials having a relatively low Charpy impact value, and as the Charpy impact value rises the influence of the area becomes more and more

Table 2.—Results of Charpy Impact Tests Made to Establish Correlation Values Between Standard ASST Charpy Impact Specimens (Keyhole Notch) and Standard ASTM Charpy Impact Specimens (Shallow "V" Notch)

(These tests were made on a 1⅜-in. Lukens plate normalized at 1450 deg. F. and drawn at 1200 deg. F., and having the following chemical composition: Carbon, 0.25%; nickel, 2.25%.)

Temp. of Test, deg. F.	Charpy Impact Value, Ft.-lbs. ASST Specimen Test 1	ASST Specimen Test 2	ASST Specimen Aver.	ASTM Specimen Test 1	ASTM Specimen Test 2	ASTM Specimen Aver.	Ratio [a] ASTM to ASST
70	31.5	38.0	34.8	52.8	58.4	55.6	1.60
0	28.6	25.9	27.2	26.7	28.1	27.4	1.01
—75	18.2	24.7	21.4	14.3	14.3	14.3	0.67

[a] The ratio of the area broken in the ASTM specimen to the area broken in the ASST specimen is 1.60, and the ratio of moment of inertia of the area under the notch in the ASTM specimen to the moment of inertia of the area under the notch in the ASST specimen is 4.10.

pronounced and the influence of the notch less and less pronounced.

As the occasion sometimes arises in which it is desirable to obtain the impact value of material in thin sections, such as pipe, in which it would not be possible to use a standard width ASST Charpy impact specimen, tests were made to determine the effect of reduced sections on the standard ASST Charpy impact specimen. In all these tests the cross section of the impact specimen normal to the axis of the keyhole notch was held at standard ASST Charpy impact specimen dimensions (10.0 mm. by 50.8 mm.). The cross sections of the specimen parallel to the notch (end view) were made 10.0 mm., 7.5 mm., 5.0 mm., and 2.5 mm. wide by 10.0 mm. high. Sketches showing the specimens in this series of tests are shown in details B, C, D, and E of Fig. 1. It will be noted that in all these specimens only the breadth of the area under the notch was varied, the depth in each instance being held at the standard ASST dimension of 5.0 mm. This meant that the reduction in moment of inertia of the specimens was directly proportional to the reduction in area.

Table 3 details the results of the correlation tests

Table 3.—Results of Charpy Impact Tests Made to Establish Correlation Values Between the Standard ASST Charpy Impact Specimen and Charpy Impact Specimens with the Standard ASST Keyhole Notch and of Standard Height But with Less than Standard Widths

(These tests were made on a 1⅜-in. Lukens plate normalized at 1450 deg. F. and drawn at 1200 deg. F. and having the following chemical composition: Carbon, \$0.25%; nickel, 2.25%.)

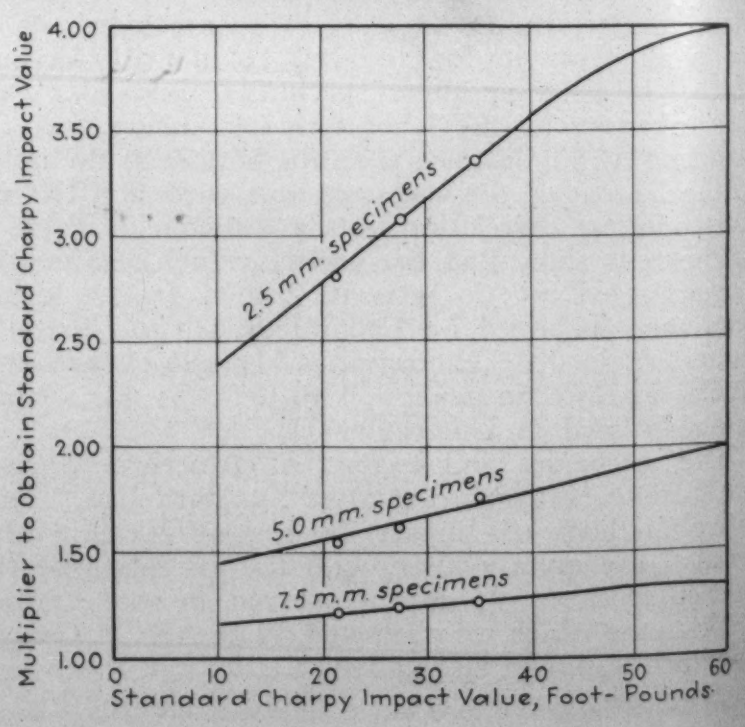
Width of Specimen, mm.	Ratio Area Broken to Standard Area	Temp. of Test, deg. F.	Charpy Impact Value, Ft.-lbs. Test 1	Test 2	Aver.	Theoretical Multiplier [a]	Actual Multiplier [b]
10.0	1.00	70	31.5	38.0	34.8	1.00	1.00
10.0	1.00	0	28.6	25.9	27.2	1.00	1.00
10.0	1.00	—75	18.2	24.7	21.4	1.00	1.00
7.5	0.75	70	30.9	24.0	27.4	1.33	1.27
7.5	0.75	0	21.9	22.1	22.0	1.33	1.24
7.5	0.75	—75	16.8	18.2	17.5	1.33	1.22
5.0	0.50	70	19.9	19.5	19.7	2.00	1.76
5.0	0.50	0	16.7	17.0	16.8	2.00	1.62
5.0	0.50	—75	13.7	13.8	13.8	2.00	1.55
2.5	0.25	70	9.2	11.4	10.3	4.00	3.38
2.5	0.25	0	8.7	9.0	8.8	4.00	3.09
2.5	0.25	—75	8.2	7.0	7.6	4.00	2.82

[a] Theoretical multiplier necessary to obtain standard impact value based on ratio moment of inertia of the area broken in specimen tested to moment of inertia of the area broken in standard specimen.

[b] Actual multiplier necessary to obtain standard impact value based on actual impact values obtained.

on the standard and reduced section ASST specimens. It will be noted, for a given reduction in area to be broken, that although the reduction in impact value is roughly proportional to the change in cross section, the reduction in impact value is also a function of the brittleness of the material. As with the ASTM specimen previously discussed, the influence of the notch is more pronounced in the more brittle specimens, and we would, therefore, expect that the more brittle the material, the less the impact value would be reduced by reducing the cross section. Fig. 3 shows the relationship between the multipliers necessary to obtain the standard ASST Charpy impact value for a

Fig. 3. Relationship Between Brittleness of Steel and Multiplier Necessary to Obtain Standard Impact Value When Testing Specimens of Reduced Width.



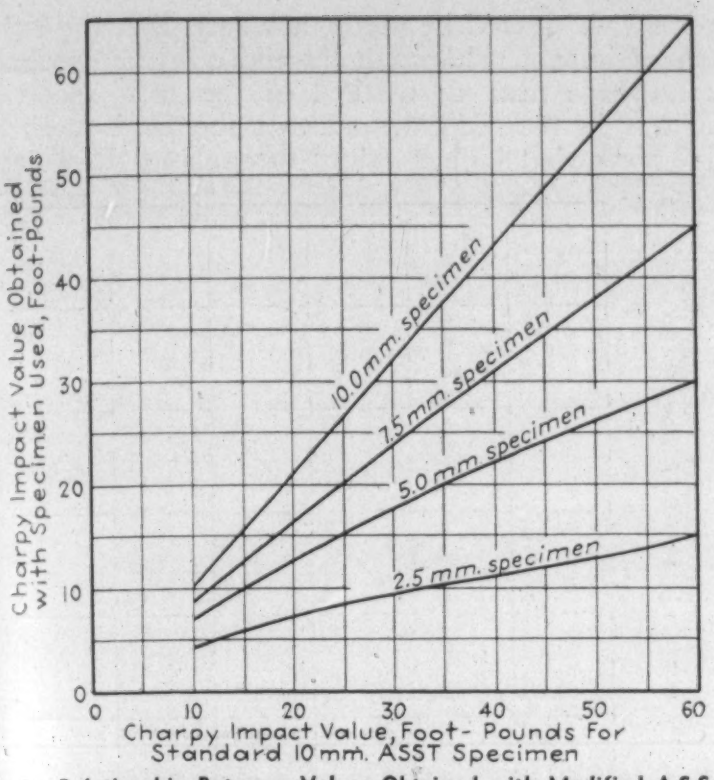


Fig. 4. Relationship Between Values Obtained with Modified A.S.S.T. Specimens and Standard Ten Millimeter A.S.S.T. Charpy Impact Specimens of Varying Degrees of Brittleness.

given specimen and the brittleness of the specimen. It will be noted that the less brittle the specimen becomes, and hence the less the effect of the notch, the more nearly does the multiplier approach the theoretical multiplier which is based on the change in moment of inertia only.

From the curves in Fig. 3 a series of curves as shown in Fig. 4 has been derived, showing the relationship between the Charpy impact value obtained on the modified specimens and the standard ASST Charpy impact specimens.

In all the foregoing tests the cross sections were reduced proportionately to the amount of inertia. In order to determine the effect of reducing the cross section without reducing the moment of inertia, additional correlation tests were undertaken. Tests were made on companion specimens taken from plates and castings of varying brittleness in order to cover as wide a range of impact values as possible for the correlation tests. Sketches of the specimens used in this series of tests are shown in details B, D, and F of Fig. 1.

The results of these correlation tests are summarized in Table 4 and portrayed graphically in Fig. 5. It will be noted that the results obtained with the modified 5.0 mm. by 10.0 mm. specimens agree quite well with the correlation previously obtained. The 5.0 mm. by 11.3 mm. specimens, which have the same moment of inertia but only half the breadth of the standard specimens, gave results somewhat lower than the results obtained with the standard specimens. Apparently there is a distinct correlation between the brittleness of the specimen, the moment of inertia, and the area to be broken under the notch. In all the notched base impact tests we have made, the values tend to approach the theoretical results based on moment of inertia as the brittleness decreases. Correlation curves for these two types of specimens with the ASST standard Charpy impact specimen were derived from the curves in Fig. 5, and are presented in Fig. 6.

Tests were also made to determine the correlation existing between the "U" notch and the keyhole notch Charpy impact specimens. Detail G of Fig. 1 shows the "U" notch specimen. Fig. 7 presents the results obtained in these correlation tests. As would probably be expected, the impact results obtained by both the "U" notch and keyhole notch Charpy impact specimens gave equivalent values.

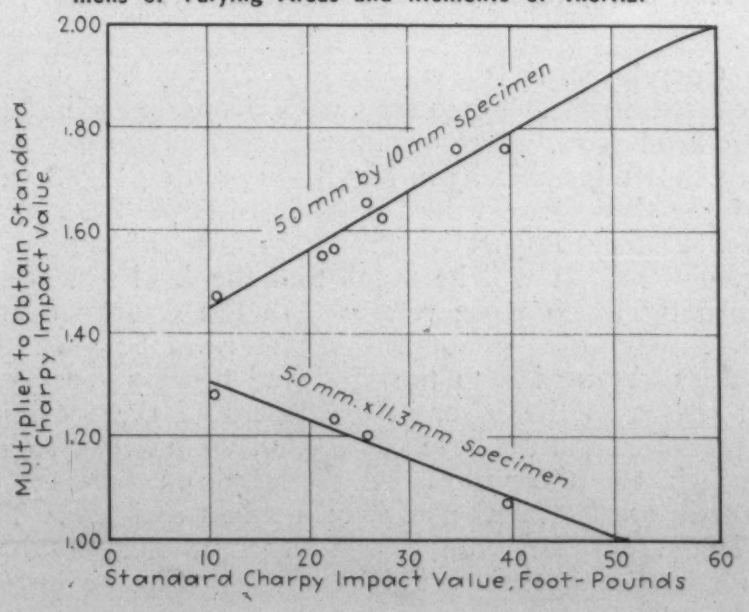
Additional tests were made to correlate the ASST standard Charpy impact specimen with the standard Izod impact specimen, shown in detail H of Fig. 1. The Izod impact specimens were 10.0 mm. square, 130 mm. long, with three notches, one notch on each of three sides of the specimens. The first notch was 28 mm. from the end of the bar and the other two notches were spaced 28 mm. on centers from the first notch. The notches were shallow "V" shaped and had a radius of 0.67 mm. at the base of the notch. The area under the notch was 10.0 mm. in breadth and 8.0 mm. in depth. The bars were supported as

Table 4.—Summarization of Tests Made to Determine the Effect of Charpy Impact Specimen Size and Shape on the Impact Value Obtained

Material Source	Temp. of Test deg. F.	Dimensions of Specimen, mm. Length	Breadth	Thickness	Dimensions Under Notch, mm. Depth	Breadth	BD^3	No. of Tests	Charpy Impact Value, Ft.-lbs. Min.	Max.	Aver.	Multiplier [a]
Plate X	70	50.8	10	10	5	10	1250	3	37.7	41.3	39.5	1.00
Plate X	70	50.8	10	5	5	5	625	3	22.0	22.9	22.4	1.76
Plate X	70	50.8	11.3	5	6.3	5	1250	3	34.6	39.6	36.8	1.07
Plate Y	0	50.8	10	10	5	10	1250	3	25.6	25.7	25.7	1.00
Plate Y	0	50.8	10	5	5	5	625	3	14.6	16.7	15.6	1.65
Plate Y	0	50.8	11.3	5	6.3	5	1250	3	19.0	23.8	21.4	1.20
Plate Z	—75	50.8	10	10	5	10	1250	3	19.9	24.6	22.4	1.00
Plate Z	—75	50.8	10	5	5	5	625	3	13.1	15.7	14.4	1.56
Plate Z	—75	50.8	11.3	5	6.3	5	1250	3	16.5	19.5	18.2	1.23
Casting W	—50	50.8	10	10	5	10	1250	3	9.8	11.2	10.4	1.00
Casting W	—50	50.8	10	5	5	5	625	3	6.5	7.6	7.1	1.47
Casting W	—50	50.8	11.3	5	6.3	5	1250	3	7.7	8.6	8.1	1.28

[a] Actual multiplier necessary to obtain standard impact value based on actual impact values obtained.

Fig. 5. Relationship Between Brittleness of Steel and Multipliers Necessary to Obtain Standard Impact Values When Testing Specimens of Varying Areas and Moments of Inertia.



cantilevers and three fractures were made on each bar, one fracture being made from each notch. The bar was brought to the correct temperature of test for each notch.

Izod and Charpy Specimens Compared

The most significant differences between the Izod and Charpy impact specimens are:

1. The Izod specimen has a shallow "V" notch with a radius of 0.67 mm. at the base of the notch, and the Charpy specimen has a keyhole notch with a radius of 1.0 mm. at the base of the notch. This means that a greater intensification of stress will be obtained in the metal under the Izod notch than in the metal under the Charpy notch.
2. The Izod specimen is tested as a cantilever and the Charpy specimen as a simple beam.
3. The Izod specimen has a breadth under the notch of 10.0 mm. and a depth under the notch of 8.0 mm., giving it an area of 80 sq. mm., and a BD^3 (given as a measure of the moment of inertia) of 5120. The Charpy specimen has a breadth under the notch of 10.0 mm., and a depth under the notch of 5.0 mm., giving it an area of 50 sq. mm., and a BD^3 of 1250. This means that the Izod specimen has 1.6 times the area and 4.1 times the moment of inertia of the Charpy specimen, indicating that the Izod specimen will tend to absorb more energy in rupture than will the Charpy specimen.

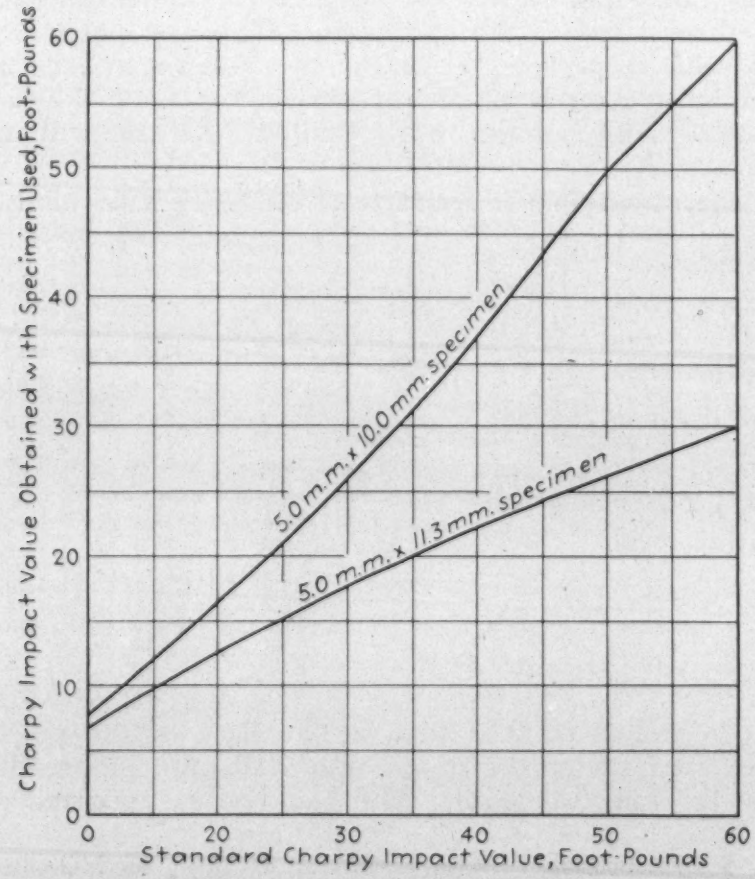


Fig. 6. Relationship Between Impact Value Obtained with Modified A.S.S.T. Charpy Impact Specimens and Standard A.S.S.T. Charpy Impact Specimens.

Correlation tests were made on 27 Izod and Charpy test specimens. Three tests were made on each of the 27 Izod bars. The results of the correlation tests are shown graphically in Fig. 8. In plotting Fig. 8, each of the three Izod values obtained was plotted against the Charpy impact value obtained with companion specimens. It will be noted that the Izod test is apparently much more erratic than the Charpy test.

It will also be noted that the ratio between the values obtained with the Izod and Charpy specimens increases as the inherent brittleness of the specimen decreases, and that the correlation values tend to approach the theoretical values based on moment of inertia as the brittleness becomes less and less. The curve is of the same general type as that obtained in correlating the ASTM and ASST Charpy impact specimens. It will be noted, however, that the reduction of impact value with the more brittle specimens is nowhere near as marked in the Izod specimens as it is in the ASTM, and that the Izod specimens give somewhat higher values throughout than do the

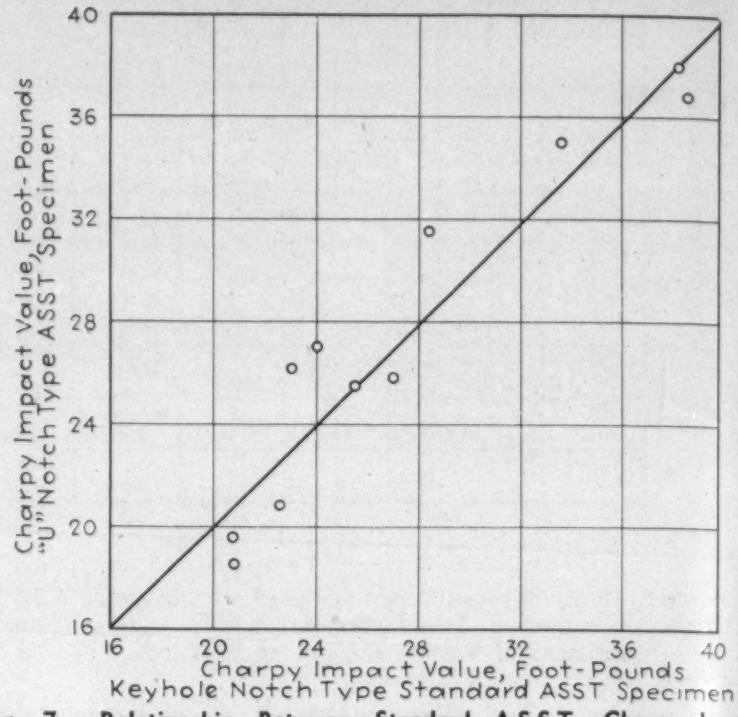


Fig. 7. Relationship Between Standard A.S.S.T. Charpy Impact Specimens (Keyhole Notch) and A.S.S.T. Charpy Impact Specimens ("U" Notch).

ASTM specimens. Both the ASTM and Izod specimens have over four times the moment of inertia of the Charpy specimen; the ASTM notch has a radius of 0.25 mm., the Izod notch has a radius of 0.67 mm., and the Charpy notch has a radius of 1.00 mm. It is, therefore, to be expected that the effect of the notch, in producing intensification of stress, would be less marked in the case of the more brittle materials with the Izod specimens than with the

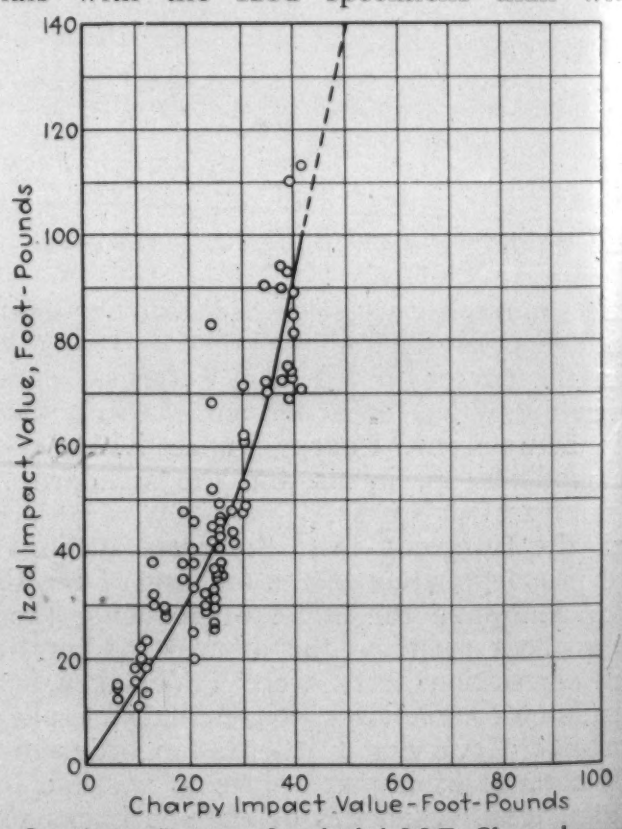


Fig. 8. Correlation Between Standard A.S.S.T. Charpy Impact Specimens and Standard Olsen Type Izod Impact Specimens.

ASTM specimens, although in both the Izod and ASTM specimens, the influence of the notch becomes more and more pronounced and the influence of the moment of inertia less and less pronounced as the specimens become more brittle.

(To be continued)

Notes in the History of Metallurgy

Russell W. Davenport

By H. W. GILLETT

THROUGH THE COURTESY of Messrs. A. J. Wadhams, and H. J. French of the International Nickel Co., we have been loaned a copy of a biography of Russell Wheeler Davenport, G. P. Putnam's Sons, 1905, 79 pages 1849-1904, with the suggestion that it might well be abstracted as one of the series of sketches on metallurgical history, inaugurated in these pages several years ago by the late L. W. Spring.

Davenport's name was new to us, as it will be to most of our readers, for he was one of the un-advertised pioneers. Yet he seems to have been the father of the heavy-forging industry in the United States.

Davenport was of an old New England family, an ancestor landing in Boston in 1637. His great-great-great grandfather was a Yale man, as was each of the intervening ancestors. Davenport was graduated from Sheffield in 1871, having stroked the Sheffield crew, and inaugurated the use of the sliding seat. The academic department of Yale looked down upon "Sheff" in those days and the Sheff engineers were not eligible for the Yale crew. But after Davenport's crews had licked the academic varsity for a couple of years, the Sheff men were declared eligible. It is considered that Davenport may fairly be called the father of Yale rowing.

His graduating thesis was on "Hot Blast Applied to Iron Melting." After a year as instructor in chemistry at Sheff, he went abroad to study at the School of Mines at Berlin, learned puddling in Silesia, and visited the important iron and steel works of England, Wales, France, Austria, Germany and Belgium.

On his return to the United States a former roommate, Chas. A. Brinley, who had been chemist at the Midvale Steel Works, was put in charge of the metallurgical department, and the vacant post of chemist was taken by Davenport in 1874.

The scientific method had been adopted at Midvale on Brinley's arrival and he was bringing order out of a chaotic condition left by Butcher, the original operator of Midvale, but not without opposition from the practical men in the works who objected to being taught by college boys. However, Brinley and Davenport succeeded in making crucible quality steel in the open-hearth, and put the plant on a paying basis, being backed up by the president, Williams Sellers. Within a year after Davenport came, the superintendent died, Brinley became superintendent and Davenport in turn moved up from the laboratory to take charge of melting.

Once the plant knew how to make really solid steel ingots, its product became popular for big forgings, locomotive axles and the like, and from the reputation thus built came the first order given by the Government to an American manufacturer for gun forgings. This order, in 1875, was for howitzers for the coast guard, used to throw lines to ships in distress.

This turned Midvale's attention to gun forgings, and

A Large Crankshaft Built Up of Several Forgings. (Courtesy of Bethlehem Steel Co., Bethlehem, Pa.)

A Large Hollow Steel Forging Ready for Closing the Ends. (Courtesy of Bethlehem Steel Co., Bethlehem, Pa.)

in 1882 they made the forgings for the Navy's first 6-in. all-steel rifled gun. Davenport became superintendent in 1882 and upon him fell the supervision of this job.

Another task was rolling the I-beams, etc., for the Brooklyn Bridge, which was done in the mill set up by Butcher but unused for many years, so that Davenport had to start from scratch, with no one at Midvale with experience in rolling.

For more than 10 years there was only one plant in the country, Midvale, which would undertake to meet the Army and Navy specifications for gun forgings. Davenport's reputation in this field was so preeminent that when, in 1888, Bethlehem decided to go into the ordnance game, Davenport was chosen as assistant to John Fritz.

When Davenport left Midvale, some 400 of the employees surrounded his house to bid him farewell, and give him a watch with a charm in the miniature likeness of a 6-in gun. Davenport's reply is given in some detail. It recounts the crisis at Midvale before Brinley's time, due to lack of "accurate chemical knowledge of the difference between good and bad steel," how the scientific method brought a reputation for quality steel, and mentions that, in his 14 years at the plant, there had never been a strike.

Bethlehem had made a huge investment in its plant for guns and armor plate. It had made arrangements with Whitworth of Manchester and Schneider of Creuzot for drawings of machinery and for aid in erecting and operating the equipment, but, even though the plant was equipped for production of larger pieces than these foreign plants, with Davenport's help it was able to put the program through without having to call for help from abroad.

Large Rough Steel Forging with Closed Ends Ready for Machining. (Courtesy of Bethlehem Steel Co., Bethlehem, Pa.)

In 1886 Bethlehem had bid on Navy contracts for gun forgings and armor plate and manufacture began in 1888, with Davenport as expert adviser. By 1889, 12-in gun forgings and 3-in diameter shafts for Navy cruisers were being made. The first armor plate, tested in 1891, proved to be the best made anywhere to that date. In 1893 Davenport became general manager at Bethlehem.

In 1894 Harvard gave him an honorary A.M. degree for his metallurgical achievements and for his services to the Government in putting the manufacture of guns and armor at Bethlehem into the front rank among nations. In 1898, Yale came across with a similar degree. In the citation, a statement from an army officer is quoted which says that, almost unaided, it was Davenport who brought the method of manufacture of steel for guns and armor to its high standard.

Technical papers from Davenport's pen appeared in the *Transactions* of the Society of Naval Architects in 1893, and in *Cassier's Magazine* in 1897.

Steel Forging of a 66-In. Pipe Section. (Courtesy of Bethlehem Steel Co., Bethlehem, Pa.)

Davenport's next step was to the Cramp Ship & Engine Building Co. in 1903, which was building for the Navy the ships upon which were used the guns and armor supplied by the firms he had helped build up. Cramp's was in need of refinancing and of new management, and Davenport was chosen to give them the necessary technical and managerial talent. After 3 months as "Expert Assistant to the Executive Committee," he became general manager. He applied methods similar to those he had used in keeping track of metallurgical material in the course of manufacture, and was making the same sort of a record as an administrator as he had previously made as a manufacturer, when he died of pneumonia after less than a year with Cramp's.

Davenport was of the era before metallurgical courses were available as such, and like several other metallurgical pioneers, he came into the industry from the chemical side and picked up his metallurgy by virtue of being well grounded in scientific thought from his chemical training. His interest was in metallurgy from the outset, as is shown by his thesis subject.

His ability and personality have their monuments in the present Midvale and Bethlehem plants, still the leaders in the production of huge forgings of high quality, and still operating under the scientific method that worked out so well as Davenport applied it.

The Role of Films in the Electrodeposition of Metals—II

A Correlated Abstract

By WALTER R. MEYER
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Concluded from the May Issue

Polishing Films

GRINDING, IN WHICH COARSE ABRASIVES are used, may be regarded almost entirely as an abrading process in which surface removal is accomplished by successive furrowing, but polishing in the metallographic sense and commercial buffing involve an entirely different method of surface alteration. The study of the mechanism of polishing has extended over the past 30 years with microscopic observations, which are augmented today by electron diffraction and photochemical technique.

Robert Hooke,[76] 270 years ago, showed that grinding with an abrasive resulted in a series of grooves which become progressively smaller and smaller as the grain size diminished. Lord Rayleigh[77] and F. Osmond and G. Cartaud[78] first indicated that polishing was a process in which the surface irregularities were smoothed out rather than ploughed away. They regarded the process as being almost a molecular one. Spring[79] and E. Cohen[80] noted differences in such physical properties as solubility, electrical nature and particularly a peculiar photographic reactance between the polished surface and the normal metallic surface.

Beilby,[81] in a series of papers from 1903 onward, as a result of microscopic observations on polished metals and non-metallic solids, concluded that the action of polishing was to cause the surface layer of metal to flow like a liquid, which congealed rapidly without crystallizing, resulting in a thin amorphous or as he termed it, "vitreous" layer. He demonstrated that even in the case of a hard brittle metal such as speculum metal, light polishing with the finger or a soft leather applied by hand is capable of imparting surface mobility to a layer of molecular thickness, which may flow over scratches or imperfections and produce a mirror finish. Tutton[82] claims that the abrasive particles which produce the mirror finish are smaller than 5000 A, and that they are two or three times the wave length of light. Adam[83] accepted Beilby's views that the polished surface is amorphous but did not consider that the metal actually liquefied in the process of polishing.

The invention of the electron diffraction camera[84] supplied a new tool for the examination of the structure of polished surfaces because of the low penetrating power of the electron, being of the order of 100 A (Fig. 3). Thus the diffraction and refraction effects are due to a surface condition and are not from the body of the metal. R. C. French[85] appears to have been the first one to use the electron diffraction camera for the study of polished surfaces. When a polycrystalline metal was polished, the characteristic ring pattern became blurred and the diffuseness increased as the polishing was continued until only two broad diffraction maxima were obtained. From this he concluded that the crystalline size of the Beilby layer was not greater than two or three unit cells and hence was essentially amorphous. J. T. Randall and H. P. Rooksby[86] also concluded that a certain amount of amorphous metal was formed on polishing.

F. Kirchner[87] suggested that the presence of only the two diffuse rings found by French could be explained without assuming the presence of amorphous metal. Kirchner stated that a polycrystalline metal surface under bombardment by electrons at a grazing angle gives sharp diffraction rings if the surface consists of small lumps which are thin enough to allow the electrons to pass through. These lumps act as a grating, but they are levelled by polishing. L. H. Germer[88] made a similar suggestion to that of Kirchner and calculated that if a polished nickel surface (inner potential of 15 volts and electron beam voltage of 50,000) consists of minute crystal faces at slightly different angles, the maximum deviation from the mean plane of the surface being one-half a degree, then the diffraction rings would be sufficiently widened to merge into one another. Darbyshire and Dixit[89] confirmed French's findings for the same and other metals. They concluded that the atoms in the polished layer undergo a very close packing, with interatomic distances much smaller than the distances in the normal crystal lattice. The abnormally small size of the atoms is believed to be due to stripping of electrons from the outer electronic shell by the polishing.

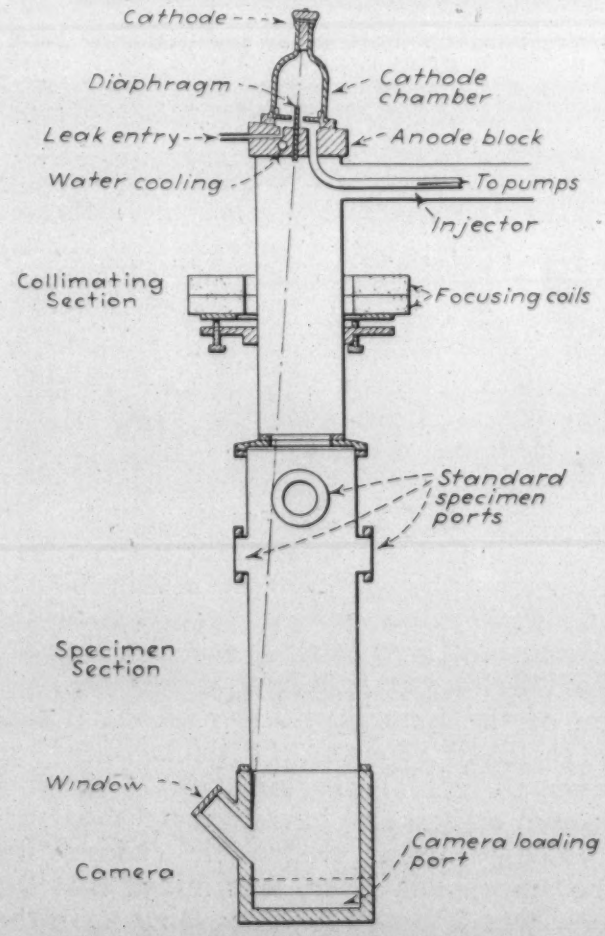

Fig. 3. Precision Electron Diffraction Camera. After G. P. Thomson and Willman.

They obtained no support for the Beilby theory for heteropolar bindings, such as in galena or pyrites.

Finch, Quarrel, and Roebuck[90] offer new evidence which they conclude definitely establishes the amorphous nature of the Beilby layer. When thin layers of zinc were deposited upon polished copper, rapid diffusion took place, but when the polishing film was previously removed by etching, the deposited zinc film

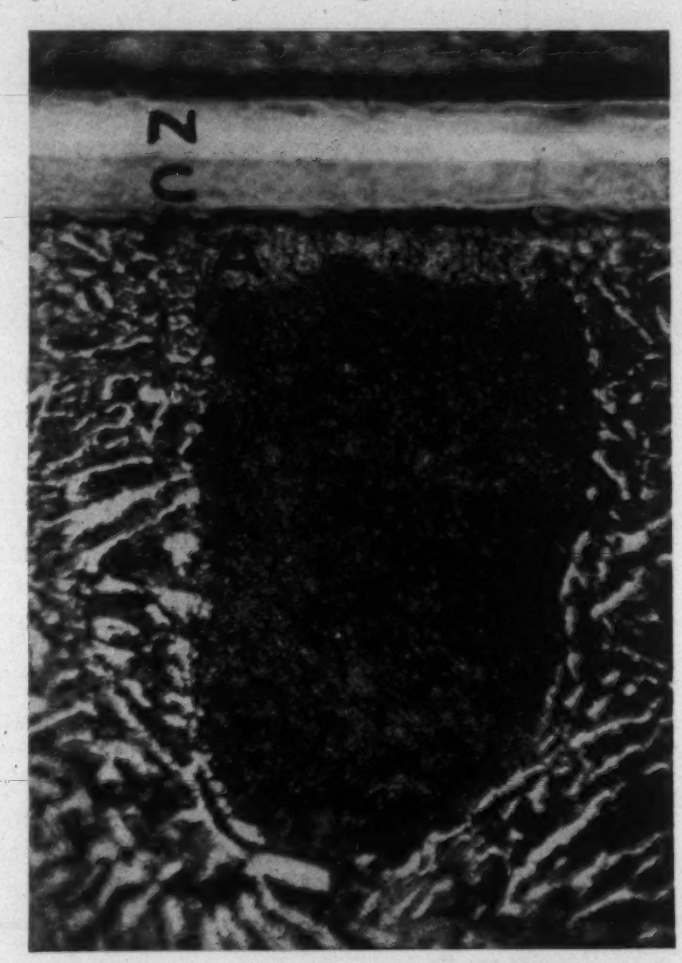

Fig. 4. Sub-Surface Effects of Polishing on Lead-Antimony Alloy. "N" is 0.0005 in Ni, "C" is 0.0005 in Cu and "A" is a zone of antimony precipitated out of solid solution of the lead crystal by polishing previous to plating. The alloy contains 7 per cent Sb and was cast in a chilled mold. After W. R. Meyer and C. Heloule.[8]

diffused at a much slower rate. With a sufficiently thick zinc deposit, the Beilby layer became saturated and the zinc film then persisted indefinitely. Thirty seconds deposition of zinc sufficed to form a permanent crystalline layer on crystalline copper, whereas a 3-minute deposition was necessary when polished copper served as a base metal.

Much weight has been put upon this paper as evidence of the amorphous nature of polished surfaces but to the writer the microcrystalline viewpoint of L. Hamburger can account for the same effects. H. Raether,[91] also using electron diffraction methods, reported that an amorphous film is formed by polishing metals. G. P. Thompson, in a discussion of the small scale structure of metals, cited evidence that the assumptions of Kirchner and Germer were false. At the symposium of the Faraday Society on metal surfaces, H. G. Hopkins[92] reported the thickness of the amorphous layer on gold to be about 30 A. with a gradual increase in crystal size below the polished surface. C. S. Lees,[93] using electrolytic etching for removal of the amorphous layer, determined that the amorphous layer was 20 to 40 A., depending upon the method of polishing (Table 2). A layer of oriented crystallites was found beneath the amorphous layer.

If the results of the electron diffraction work on the structure of polished metal surfaces are accepted, we must certainly regard the Beilby layer to be amorphous. It must be remembered, however, that the electron diffraction results are of doubtful significance when the particle size is of the order of a few atomic dimensions. If the amorphous state is regarded as completely isotropic, then we must withhold judgment on the Beilby layer, but if a quasi-isotropic, colloidal state is regarded as amorphous, then the amorphous nature of the Beilby layer has been established by several methods of attack. In this connection, Kirchner[94] reported the interesting observation that when polycrystalline gold films of about 100 A. thickness were subjected to rapid electron streams, on the one hand by transmission and on the other by reflection, the transmitted rays furnished sharp interference rings, whereas the reflected rays gave only two very diffuse broad maxima, of the same nature as those which can be obtained from polished surfaces! The inference as to the validity of deductions from the work with reflected electrons is obvious.

The works of L. Hamburger,[95] have been generally overlooked in the study of the structure of the Beilby layer. Hamburger's conclusions, which were based on ultra-microscopic "development" of polished surfaces, reconcile the amorphous and crystalline viewpoints of the Beilby layer. Hamburger's conclusions in brief are:

Table 2. Thicknesses of the Beilby Layer with Different Polishing Technique—After C. S. Lees[93]

Method of polishing	Depth	Structure	Approx. size of crystals	Voltage
(*a*)	0 A.	Amorphous		21 kV.
	45	Oriented	170 A.	21
	190	Non-oriented	130	15¼
(*b*)	0	Amorphous		20 kV.
	27	Oriented	90	19
	55	Oriented	90	17
	80	Oriented	90	21
	130	Oriented	90	19
	190	Oriented	90	23
	300	Oriented	90	21
	460	Non-oriented	130	24
(*c*)	0	Oriented	20	23 kV.
	70	Oriented	70	28¼
	175	Oriented	70	22
	850	Non-oriented	100	24

The crystals in the oriented layer are not much smaller than the non-oriented crystals beneath. In the case of the specimen polished by method (*a*), the thickness of the oriented layer is about equal to the size of the crystals of which it is composed.

1. Polishing is primarily a chip removing process accompanied by absorption effects. The size of the chips is between 3 and 30 atoms.
2. In a later phase of polishing, a portion of the "flowing" amicrons adhere to a portion of the worked surfaces, notably in holes and crevices. Actual melting of the surface is not implied. In the resultant mirror-like surface, the mean particle size is small in comparison with the wave length of visible light but large in relation to atomic dimensions.
3. The carefully polished surface of a crystalline substance at room temperature consists of laminae of oriented crystallites of microscopic magnitudes which show a frequency of particle size. The polish extends inward to the basis metal by a transition layer of larger crystals. The nature of the polished layer is complicated through absorption, impurities, the presence of distorted transition zones between the crystallites, and more generally by a physical metastability. Hamburger's interpretation would account for the diffuseness of the electron diffraction patterns by the poor resolving power of the micro-crystals.

The work mentioned thus far has concerned itself chiefly with the structure a few hundred Ängstrom units thick. The sub-surface effects of polishing are greater the harder the degree of work upon the surface (Fig. 4). The X-ray is obviously more suitable for studying the sub-surface effects of polishing, machining, etc. W. Boas and E. Schmid,[96] using Laue reflection diagrams of cut and polished copper, zinc, and aluminum, measured the depth of penetration of the effects of polishing. A distortion effect penetrated more than 2.5×10^5A below the surface of polished copper. The transition from the oriented crystallites to the distorted unoriented crystals was

sharp, but the transition from the distorted crystals to the undeformed basic crystals was gradual. Bito[97] studied the surface hardening effects from polishing carbon steels with alundum wheels. For carbon steels the results were negative, but with a special armor plate a martensitic structure was obtained to a depth of 5×10^6A. from the surface. The Shore hardness increased from 30 to about 70.

In concluding the discussion of the effects of polishing, the slightly irrelevant work of Ananiaschwili and Gogoberidse[98] on the nature of twinned crystal interfaces may be mentioned. From Debye pictures the authors concluded that a finely crystalline layer exists between adjacent twin crystals, contradicting previous assumptions of an amorphous layer or of direct contact of twins.

The mode of formation and the probable structure of passive films and polishing films have been described. We will now consider the effects of the substrate on spluttered films and the effects of the basis metal and its films upon the structure of the electrodeposit.

Structures of Thin Films on Various Sub-Strates

A short review of thin films deposited chiefly by cathodic spluttering will be presented because of the possible analogy between their structure and the structure of the first films of comparable magnitude which are deposited by electro-deposition. Zofja Debinska,[99] studying thin films of platinum, copper, and nickel a few millimicrons in thickness, found a marked orientation between the microcrystals and the material carrying the film, and the regularity of orientation was somewhat dependent upon the nature of the sub-strate. G. P. Thomson,[100] using his electron diffraction camera, determined that gold spluttered upon gold and quartz was deposited in a polycrystalline condition. Thomson, Stuart, and Murison[101] deposited films of platinum in various gases by cathodic spluttering and found that the small crystals are deposited with one face oriented parallel to the face of the specimen, the crystal being otherwise arranged at random. From the width of the diffraction rings, it was calculated that the size of the crystal was of the order of 5×10^{-7} cm.

M. J. Gen and co-workers[102] deposited films in vacuo down to temperatures as low as —183 deg. C. and found that the deposited metallic layers showed structures similar to the ordinary metals, although dispersion was evident to an extreme extent. Lassen and Bruek[103] condensed very thin silver films in a vacuum upon rock salt and decided that the orientation and formation of silver monocrystals depended upon the orientation and the temperature of the rock salt. In a recent publication, G. Tamman[104] reported that the structure of thin metal films is always crystalline, but that, owing to the minute size of the particles, which are mostly mono-crystals, the number of crystalline centers is very great. It may thus be seen that the evidence indicates that the basis metal has definite orientive effects upon the crystals of thin films and that these films are usually crystalline.

Relationship Between Structure of Basis Metal and Electrodeposit

As recently as 1922, H. S. Sand[105] and W. E. Hughes[106] were skeptical of the influence of the crystalline structure of the basis metal upon the structure of the electrodeposit. Huntington[107] first noticed that the microstructure of the copper deposit could be influenced by the structure of the copper upon which it was deposited. In 1916, G. B. Hogaboom[108] called attention to the probable effects of the basis metal upon an electrodeposit, and in 1921[109] he pointed out that one of W. Blum's photomicrographs[110] of alternately deposited metals showed reproduction of the rolled copper base in the electrodeposit. How well the viewpoint of Hogaboom at that time has been substantiated today!

W. Blum and H. S. Rawdon,[111] two years later, presented photomicrographs of copper electrodeposits on cast and rolled copper in which an extension of the crystals of the basis metal was clearly evident in the deposited copper. A nitric acid dip was used to remove polishing films from the basis metal to expose the normal crystals to the deposited copper (Fig. 5). When this dip was not used, continuation of the crystal structure of the basis metal by the copper coating was not discernible. Some of the photomicrographs of this paper are reproduced. A. K. Graham[112] repeated this observation for copper on copper, and for copper on brass, but was uncertain about the results for nickel upon nickel. During the deposition of copper upon

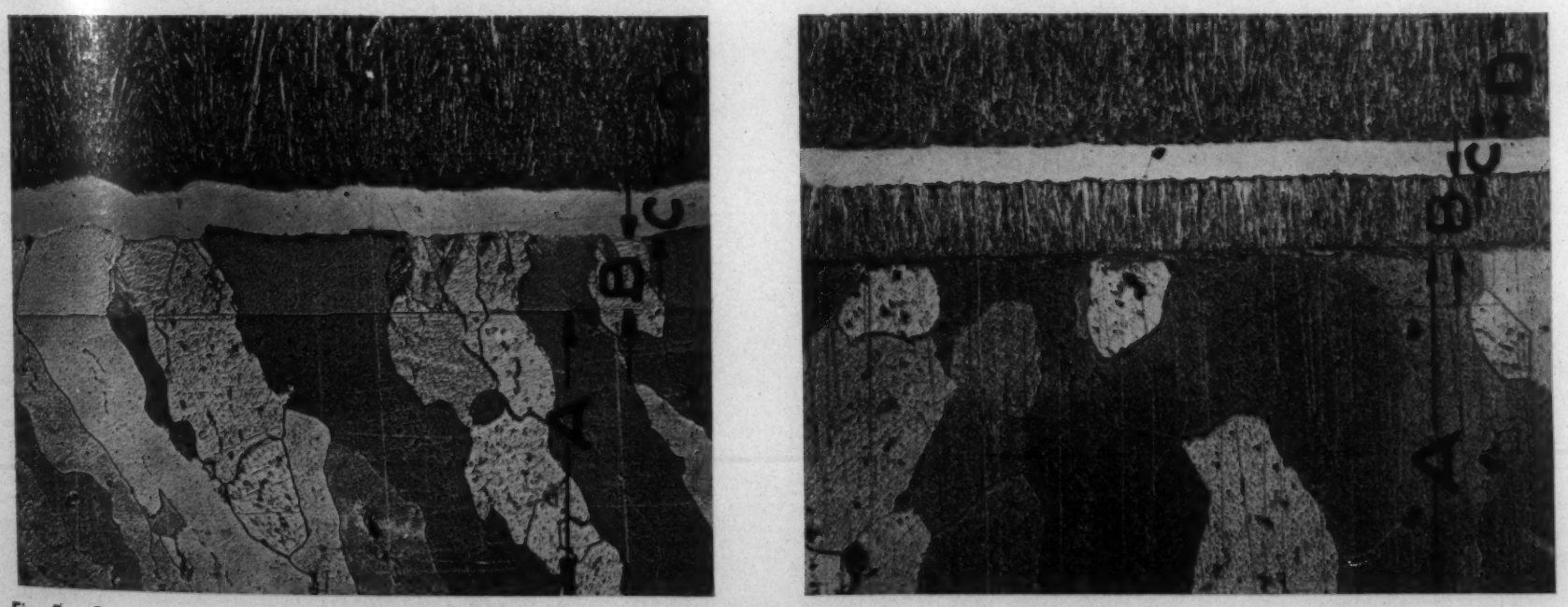

Fig. 5. Continuation of Crystal Structure of Cast Copper by Electrodeposited Copper. The copper in the photomicrograph (left) was etched with nitric acid before it was copper plated. The continuation of the basic metal by the copper plate is clearly observed. The cast copper in the photomicrograph (right) was not etched before being copper plated. No continuation of the basic metal crystals is visible. For both photomicrographs zone "A" is the basic cast copper, zone "B" is the electrodeposited copper, zone "C" is nickel plate and zone "D" is mounting metal. After W. Blum and H. S. Rawdon, III.

copper, the current was broken for a water rinse and a cyanide dip, but the continuation of the crystal structure was not interrupted. A. W. Hothersall,[113] in 1933, published a photomicrograph of nickel electroplated upon nickel, where a distinct extension of the basis metal crystals into the electrodeposit was noticeable.

In March of this year, (1935), Hothersall [114] published some excellent examples of extension of crystal growth of the basis metal by the electrodeposit of nickel upon nickel, iron upon nickel, tin upon tin, and tin upon a tin-antimony alloy (99:1), and a suggestion of complete continuation of tin deposited upon annealed copper. The results clearly showed that a continuation of a basis metal structure is possible, (a) when deposit and basis metal belong to the same crystal system, over a range of differences in lattice parameters (e.g. from —2.4 to plus 12.5 per cent difference), (b) when deposit and basis metal belong to different systems. Thus, tetragonal tin was shown to continue the microstructure of copper (face centered cubic) and copper to continue that of beta brass (body centered cubic).

W. A. Wood[115] studied, by X-ray methods, the crystal orientation of the electrodeposited layer caused by the cathode. When copper or nickel was deposited upon rolled copper, the orientation of the deposit was the same as the basis metal for small current densities. When the current was increased, less orientation resulted.

G. Tamman and M. Straumanis,[116] three years previous to Wood, obtained similar results for copper deposited upon copper. On polished copper cathodes, copper is deposited in small crystals, the size and orientation of which differ from that of the crystals of the cathode, but if it is deposited upon etched copper the orientations of the crystals of the basis and of the electro-deposited copper are the same. Higher current densities tended to cause non-orientation.

The adhesion of the plated coating is highest when extension of crystal growth occurs. Polishing films, passive films, and other films that have been discussed will prevent this extension. Industry has realized the practical value of the scientific findings which we have considered, and careful preparation of the basis metal, previous to electroplating, is a general practice. In view of the faithful reproduction of the basis metal crystals by the plated coating, a coarse coating will result when the basis metal is coarse and a fine crystalline coating when the basis metal crystals are fine.

In decorative plating, the higher degree of adhesion produced by etching the basis metal may have to be forsaken in order to secure a coating of the desired brilliance. The effects of the basis metal crystals are gradually overcome as the deposit increases in thickness, especially when deposition occurs at high current densities or from complex ion solutions such as the common cyanide baths. When the layer of cold-worked metal from polishing is not removed, peeling may occur between this layer and the underlying larger crystals rather than between the electro-deposit and the basis metal interface. Thus Hothersall[117] found a layer of brass adhering to a nickel electrodeposit that had been pulled away from the basis metal.

G. Dubpernell[118] recommended a nitric-sulphuric acid bright dip to remove this film from polished brass and consequently to materially increase the adherence of the electrodeposit. W. R. Meyer and C. Helmle[119], by determining weight loss values in the commercial cleaning and acid dipping of metals, calculated that the Beilby layer was removed in most cases, so that the layer of cold worked oriented crystallites was exposed to the plating solution.

The properties of metals in thin films appear to vary from the metal in bulk. H. Murman[120], using an optical method, found that the electrical conductivity of metallic deposits decreased with decreasing thickness. A. Jagersberger[121] arrived at the same conclusion and R. Bosworth[122] recently determined that the electrical resistance of thin films of electrodeposited nickel, 0.08 microns thick, was twice the normal value. A vast field of study still remains on the nature, properties, and specific influences of metal films, but we may feel justly proud of the progress that has been made within the last ten years.

Films on Electrodeposits and Unplated Metals

Some data on the role of film formation on plated coatings and unplated metals will be presented. The abstraction has not been complete in this field, so commercial aspects of film formation will be considered.

Cadmium, although an excellent rust protective metal for coating iron, will discolor rapidly when exposed to certain chemical influences. This has proved particularly troublesome in the cadmium plating of merchandise which must maintain a good surface appearance. G. Soderberg[123] stated that the discoloration of cadmium is accelerated by exposure to moist, uncirculated air, particularly in the presence of ammonia fumes formed by the disintegration of cyanide or ammonium salt residues on the plate. Immersion in a chromic acid solution is recommended to prevent the tarnishing. This solution removes the offending ammonium salts and probably coats the cadmium with a passive film, as cadmium which has been dipped in this solution and brushed, will tarnish more readily than the dipped but unbrushed cadmium.

The salt spray resistance of zinc coatings or zinc alloys can be materially increased by immersion in dichromate solutions although, unlike cadmium, a distinct discoloration of the zinc surface results. The color usually varies from a light yellow to gray. J. Schulein[124] recommended an alternating current treatment in a chromic acid bath to increase the corrosion resistance of zinc. This treatment produces a deep black color.

The surface discoloration of silver has ever been a problem, especially in atmospheres strongly contaminated with hydrogen sulphide[125]. A passivation treatment,[126, 127, 128] in which the silverware is immersed in chromates or other strong oxidizing agents, will markedly increase the resistance of silver to tarnishing from hydrogen sulphide, although the surface appearance of the silver remains unchanged. Thin films of electroplated rhodium[129] have also been used to protect silver from tarnishing.

Owing to the growing importance of Elektron, a magnesium base alloy, used in aircraft engineering, the problem of increasing its corrosion resistance, especially in sea water, has received considerable attention. Effects of various reagents as potassium dichromate, nitric acid, permanganates and other chemical reagents have been studied by W. O. Kroenig and G. A. Kostylev[130]. The dichromate and nitric acid solutions appear to be most promising. G. I. Finch and A. G. Quarrell[131], using the electron diffraction camera for study of the oxides which form on magnesium, determined that they exhibit abnormal crystal structure and that heating the basis metal caused preferential orientation. H. G. Hopkins[132], in a recent study of the films formed on magnesium by the dichromate process[133], determined that the film consists of small

crystals oriented at random with respect to the surface, being probably hexagonal MgO.

The anodic treatment of aluminum has spread rapidly in the past few years and now it is one of the important branches of the electrolytic coating of metals. In this country alone, several millions of pounds of aluminum are being annually anodically treated[134]. The earliest reference to oxide films on aluminum is dated 1857 and covers the work of Buff[135]. In 1904, Mott, Zimmerman, and Corbino[136] conducted a series of measurements on film thickness and Gunther Schultz and his co-workers[137] in 1906-7 studied the potential drop of the oxide film on the aluminum surface. Five years later Baristo and Mercer[138] substantiated the work of Gunther Schultz.

Skinner and Chutt[139], Fitch[140], Meserve[141], Dunham[142], and Lilienfield, Appleton and Smith[143] made important contributions to the study of the anodic coating. The last named authors explained the potential drop in terms of work-function and assumed that the film is composed of mono-molecular strata, each stratum containing one layer of bi-polar molecules in a more or less organized condition. The insulating value of the film was related to the electro-osmotic effect by Müller and Konopicky[144] and Dobias and coworkers[145]. The early investigators were only aware of the dielectric properties of the anodic film. Bengough and Stuart[146] found new uses for the anodic film, while Flick[147] in 1925, discovered the absorptive properties of the coating, making possible the colored finishes by use of certain organic dyes.

Various electrolytes have been recommended for the anodic treatment, for example: Chromic acid,[147] oxalic acid,[148, 149] which requires high voltages, chromic and oxalic acids[150], and sulphuric acid, which was recommended by Tosterud[151] for hard abrasion resistant coatings. Bengston[152] discovered that boiling water would effectively seal the oxide coatings and prevent them from staining and dyeing. Such treatment was shown by X-ray examination to change at least part of the amorphous alumina, originally formed, into crystaline alpha-mono-hydrate, the change being also accompanied by a marked increase in corrosion resistance. It has been shown possible[153] to further increase the corrosion resistance of the coatings by the absorption of such substances as silicates or chromates.

We have just completed a general survey of the role of films in electrodeposition in relationship to the basis metal and to the coatings themselves. The increase in the quality of commercially finished articles such as chromium-plated ware may be justly attributed to the researches which we have considered.

The commercial development of corrosion resistant finishes, the use of bright deposits which do not require buffing, the adhesion of plated coatings, and the efficiencies at the anode and cathode are all related to film formation. Our progress in the study of these films will be reflected in the solution of these problems.

Bibliography (Concluded)

[76] Robert Hooke. *Micrographia*, 1665, Observation II.
[77] Lord Rayleigh. *Proceedings*, Royal Institution (London), Vol. 16, 1901, page 563. *Nature*, Vol. 64, 1901, page 385.
[78] F. Osmond and G. Cartaud. *Revue Generale des Sciences*, Vol. 16, 1905, page 51.
[79] Spring. *Bulletin*, Academie Royal des Sciences de Belgique, 1903, page 1033.
[80] E. Cohen. *Ingenieur*, The Hague, Vol. 25, 1910, page 250.
[81] G. T. Beilby. *Proceedings*, Royal Institution (London), Vol. 72, 1903, pages 218, 226. *Philosophical Magazine*, Vol. 8, 1904, page 258. *Journal*, Society of Chemical Industry, Vol. 22, 1903, page 1166. *Journal*, Institute of Metals, Vol. 6, 1911, page 5. Aggregation and Flow of Solids, Macmillan and Co., New York, 1921.
[82] A. E. Tutton. Crystallography and Practical Crystal Measurement. Macmillan and Co., New York, 1922.
[83] Adam. The Physics and Chemistry of Surfaces. Oxford Press, London, 1930.
[84] Thomson and Fraser. *Proceedings*, Royal Society (London), Vol. 128, 1930, page 641.
[85] R. C. French. *Nature*, Vol. 129, 1932, page 169. *Proceedings*, Royal Society (London), Vol. 140, 1933, page 637.
[86] J. T. Randall and H. P. Rooksby. *Nature*, Vol. 129, 1932, page 280.
[87] F. Kirchner. *Nature*, Vol. 129, 1932, page 545.
[88] L. H. Germer. *Physical Review*, Vol. 43. 1933, page 724.
[89] J. A. Darbyshire and K. R. Dixit. *Philosophical Magazine*, Vol. 16, 1933, page 961.
[90] Finch, Quarrell, and Roebuck. *Proceedings*, Royal Society (London), Vol. 145, 1934, page 676.
[91] H. Raether. *Die Naturwissenschaften*, Vol. 21, 1933, page 547.
[92] H. G. Hopkins. *Transactions*, Faraday Society, Vol. 31, 1935, page 1095.
[93] C. S. Lees. *Transactions*, Faraday Society, Vol. 31, 1935, page 1102.
[94] F. Kirchner. *Transactions*, Faraday Society, Vol. 31, 1935, page 1114.
[95] L. Hamburger. *Zeitschrift für Metallkunde*, Vol. 25, 1933, page 29. 29.
[96] W. Boas and E. Schmid. *Die Naturwissenschaften*, Vol. 20, 1932, page 416.
[97] Kaseji Bito. *Bulletin Army Ordnance*, Japan, Vol. 7, 1928, page 73.
[98] E. G. Ananiaschwili and D. B. Gogoberidse. *Physikalische Zeitschrift der Sowjetunion*, Vol. 6, 1934, page 184.
[99] Zofja Debinska. *Polskiego Towarzystwo Fizycznego*, Vol. 4, 1929, page 59.
[100] G. P. Thomson. *Proceedings*, Royal Society (London), Vol. 128, 1930, page 649.
[101] G. P. Thomson, N. Stuart and C. H. Murison. *Proceedings*, Physical Society (London), Vol. 45, 1933, page 381. *Nature*, Vol. 129, 1932, page 545.
[102] M. I. Gen, I. Zelmanoff, and A. I. Schalnikoff. *Physikalische Zeitschrift der Sowjetunion*, Vol. 4, 1933, page 825.
[103] H. Lassen and L. Brück. *Annalen der Physik*, Vol. 22, 1935, page 65.
[104] G. Tammann. *Annalen der Physik*, Vol. 22, 1935, page 73.
[105] H. S. Sand. Fourth Report on Colloid Chemistry, Department of Science and Industrial Research, London, 1921, page 353.
[106] W. E. Hughes. Electrodeposition of Iron, *Bulletin 6*, Department of Science and Industrial Research, London, 1922, page 36.
[107] Huntington. *Transactions*, Faraday Society, Vol. 1, 1905, page 324.
[108] G. B. Hogaboom. *Transactions*, American Electrochemical Society, Vol. 29, 1916, page 369.
[109] G. B. Hogaboom. *Transactions*, American Electrochemical Society, Vol. 40, 1921, page 318.
[110] W. Blum. *Transactions*, American Electrochemical Society, Vol. 40, 1921, page 307.
[111] W. Blum and H. S. Rawdon. *Transactions*, American Electrochemical Society, Vol. 44, 1923, page 305.
[112] A. K. Graham. *Transactions*, American Electrochemical Society, Vol. 44, 1923, page 427.
[113] A. W. Hothersall. *Transactions*, American Electrochemical Society, Vol. 64, 1933, page 74.
[114] A. W. Hothersall. *Transactions*, Faraday Society, Vol. 31, 1935, page 1242.
[115] W. A. Wood. *Proceedings*, Physical Society (London), Vol. 43, 1931, page 138
[116] G. Tammann and M. Straumanis. *Zeitschrift für anorganische und allgemeine Chemie*, Vol. 175, 1928, page 131.
[117] A. W. Hothersall. *Journal* Electroplaters' and Depositors' Technical Society, Vol. 7, 1932, page 115.
[118] G. Dubpernell. *Metal Cleaning and Finishing*, Vol. 4, No. 3, 1932, page 133.
[119] W. R. Meyer and C. Helmle. *Monthly Review*, American Electroplaters' Society, Vol. 22, Feb. 1935, page 29.
[120] H. Murman. *Zeitschrift für Physik*, Vol. 89, 1934, page 426.
[121] A. Jagersberger. *Zeitschrift für Physik*, Vol. 87, 1934, page 513.
[122] R. C. Bosworth. *Transactions*, Faraday Society, Vol. 30, 1934, page 549.
[123] G. Soderberg. *Metal Cleaning and Finishing*, Vol. 4, No. 10, 1932, page 561.
[124] J. Schulein. *Transactions*, American Electrochemical Society, Vol. 66, 1934, page 223.
[125] Anonymous *Oberflächentechnik*, Vol. 5, 1928, page 235. *Korrosion und Metallschutz*, Vol. 5, 1929, page 164.
[126] E. Raub. *Mitteilungen des Forschungs Instituts und Probieramts für Edelmetalle*, Vol. 8, 1934, pages 61 and 77. Deutsches Reich Patent No. 572,324.
[127] Kurt Fischbeck. *Zeitschrift für Elektrochemie*, Vol. 37, 1931, page 593.
[128] K. Assman *Chemische Zeitschrift*, Vol. 59, 1935, page 217.
[129] C. G. Fink and G. C. Lambros. *Transactions*, American Electrochemical Society, Vol. 63, 1933, page 181.
[130] W. O. Kroenig and G. A. Kostylev. *Transactions*, Central Aero-Hydrodynamical Institute U. S. S. R., No. 128, 1932, page 1.
[131] G. I. Finch and A. G. Quarrell. *Proceedings*, Royal Society (London), Vol. 141, 1933, page 398.
[132] H. G. Hopkins. *Journal*, Institute of Metals, Vol. 57, 1935, page 365.
[133] H. Sutton and L. LeBrocq. *Journal*, Institute of Metals, Vol. 57, 1935, page 343
[134] H. K. Work. *Monthly Review*, American Electroplaters' Society, Vol. 22, April, 1935, page 32.
[135] H. Buff. *Annalen der Chemie*, Vol. 102, 1857, page 269.
[136] W. R. Mott. *Electrochemical Industry*, Vol. 2, 1904, page 446.
[137] G. Schultz. *Annalen der Physik*, Vol. 21, 1906, page 929.
[138] G. E. Baristo. *Transactions*, Faraday Society, Vol. 8, 1912, page 232.
[139] C. Skinner and L. Chutt. *Transactions*, American Electrochemical Society, Vol. 26, 1914, page 137.
[140] A. L. Fitch. *Physical Review*, Vol. 19, 1917, page 15.
[141] W. E. Meserve. *Physical Review*, Vol. 30, 1927, page 215.
[142] E. M. Dunham. *Physical Review*, Vol. 33, 1929, page 819.
[143] J. Lilienfield, L. Appleton and W. Smith. *Transactions*, American Electrochemical Society, Vol. 58, 1930, page 225.
[144] W. Müller and K. Konopicky. *Zeitschrift für physikalische Chemie*, Vol. 141, 1929, page 343.
[145] A. Dobias. *Zeitschrift für Physik*, Vol. 61, 1930, page 852.
[146] Bengough and Stuart. U. S. Patent No. 1,771,910.
[147] Flick. U. S. Patent No. 1,526,127.
[148] Kujirai and Ueki, U. S. Patent No. 1,735,286.
[149] H. Work. U. S. Patent No. 1,965,684.
[150] H. Schmitt. *Hauszeitschrift und Erftwerk für Aluminum*, Vol. 4, 1932, page 79.
[151] Tosterud. U. S. Patent No. 1,900,472.
[152] Bengston. U. S. Patent No. 1,869,041-2.
[153] Edwards. U. S. Patent No. 1,946,151-3.

THE EVAPORATION OF METALS

A Correlated Abstract

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ONE USUALLY ASSOCIATES the terms "evaporation," "vapor pressure," and "fractional distillation" with such things as water solutions, oils, etc., and seldom thinks of these terms as having any practical importance as applied to metals. Yet the number of commercial and scientific processes in which the vapor pressure of metals assumes a dominant role is steadily increasing. In some cases vapor pressure effects are used to gain desired ends, while in others they are unavoidably present in the process and must be handled in the best way possible.

The nuisance value of vapor pressure has long been appreciated by the brass industry where the loss of zinc by oxidation and volatilization has led to the widespread adoption of enclosed type electric melting furnaces.[1] The high vapor pressure of zinc is, however, not an entirely unmitigated evil; Genders and Bailey[2] state that the high vapor pressure of zinc prevents the solution of other gases at brass casting temperatures and thus promotes sounder castings. This is particularly true of the 70:30 type brass.

Open-hearth men are familiar with the fact that zinc coated scrap may be used without fear of contamination while tin coated scrap must be avoided. The explanation for this lies in the fact that, at steel making temperatures, zinc has an extremely high vapor pressure, making its elimination through volatilization and subsequent oxidation inevitable, while tin at the same temperature with its lower vapor pressure is not entirely eliminated.

The chemical properties of sodium present it as an attractive possibility as a deoxidizer for steel; however, the technical difficulties in introducing it, due to its high vapor pressure, have not yet been overcome.[3]

Among the oldest commercial processes in which vapor pressure-temperature characteristics of metals have been deliberately utilized are the extraction of the metals Zn[4], Cd[5], and Hg[6]. The ores of these metals are mixed with proper reducing fluxes and the reduced metals are distilled into condensers. The purity of the reduced metal, its form, and the heat requirements of the necessary furnaces as well as temperature requirements in the condenser are all dependent on a knowledge of the vapor pressure-temperature relation for the various metals.

The vapor pressure of metals in the solid state is also commercially important; the universal use of tungsten[7] rather than molybdenum for lamp filaments is due largely to the difference in vapor pressure at operating temperatures. Molybdenum with its relatively high vapor pressure evaporates much more rapidly than tungsten and thus shortens the life of the lamp.

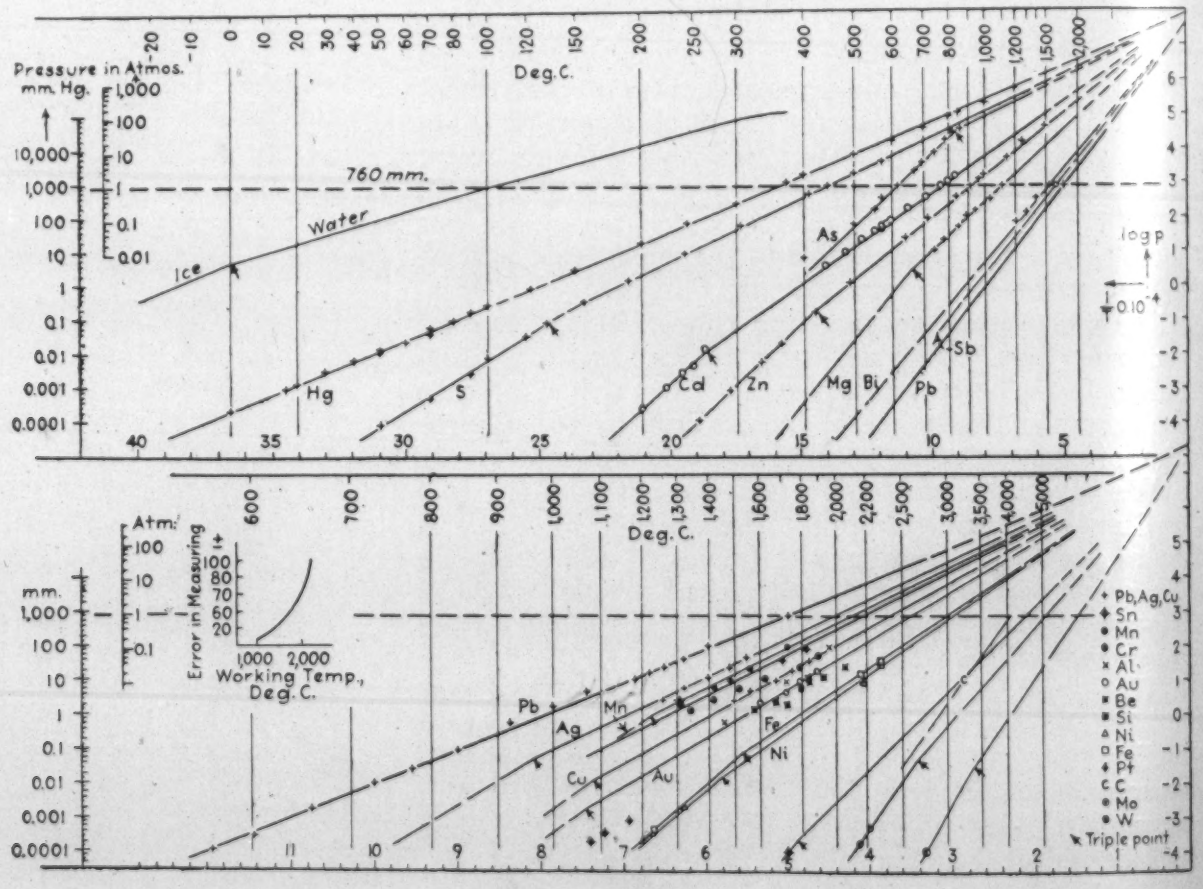


Fig. 1. Relation Between Vapor Pressure and Temperature of Metals between —20 and 5000° C.

Whatever the applications of vapor pressure may be, an accurate knowledge of vapor pressure-temperature relation is essential for complete control. Recently Leitgebel[8] has collected what he believes to be the most reliable data on 24 metals and published the results in the form of a convenient chart. This chart is reproduced in the illustration. Leitgebel remarks that the data on higher boiling metals is not as reliable as that for the lower boiling ones.

In the chart on the upper abscissae are plotted temperatures in degrees centigrade while on the lower are the reciprocals of the absolute temperature. The ordinates give the vapor pressure both in atmospheres and in millimeters of mercury, the scales being complete only in the regions where they are customarily used. It is to be noted that the pressures are on a logarithmic scale. The vapor pressure curves for the various metals are plotted in ascending order of their respective boiling points, that is, the temperature at which the vapor pressure of the metal is equal to one atmosphere. This relation is shown by the dashed line on the chart. Vapor pressure curves for carbon and water are also given for comparison.

It is to be noted that there is a change in slope of the curves at the melting point as indicated by the arrows. From this chart it is easy to see why the action of zinc and tin in molten steel is different, as mentioned above. At steel making temperatures (1600°C) Zn has a vapor pressure of around 50 atmospheres while the vapor pressure of Sn is less than 0.1 atmospheres. Here it must be remembered that the vapor pressure values, as read from the curves, are for pure metals. For alloys such as Fe-Zn the vapor pressure due to the zinc in the molten alloy will be approximately proportional to the mol per cent of zinc present or more roughly proportional to weight per cent of zinc. That is, if there was 0.1 per cent zinc present in a steel bath instead of having a vapor pressure of 50 atmospheres it would be 0.001 x 50 or 0.05 atmospheres. If an inter-metallic compound is formed, it will have a characteristic vapor pressure different from either of its constituents at the same temperature. Evidence of this sort led Chipman[9] to the conclusion that the carbon in liquid steel is present as a carbide of iron and not as atomic carbon.

The Fractional Distillation of Metals

One of the most useful applications of vapor pressure relations is in the purification of metals by distillation or sublimation. This process is not only indispensible for scientific purposes but has important commercial aspects. Usually metals of lower boiling point are distilled under atmospheric pressure either in air or non-oxidizing atmosphere while higher boiling metals are distilled in vacuum in order to take advantage of the greater rate of evaporation and while the vapor pressure of metals is unaffected by the external pressure, whether it be vacuum or atmospheric, the rate of evaporation is affected a great deal. Fonda[10], Langmuir[11], and Jones, Langmuir and Mackay[12], who have done a good deal of theoretical and experimental work on the rate of evaporation of various metals, report that the rate of evaporation of tungsten under atmospheric pressure is only about 2 per cent of its rate in vacuum. This work incidentally led to the adoption of the nitrogen filled incandescent lamp.

Among lower boiling metals which are purified by distillation under atmospheric pressure, zinc, cadmium and mercury are the most important commercially. Small, but commercially important amounts of barium are distilled under vacuum for use in connection with magnesium as a "getter" in the vacuum tube industry[13]. Magnesium[14] itself has been purified commercially in vacuum by sublimation.

Kroll[15] has done important ground work on a laboratory scale in determining what might be expected in the vacuum purification of metals. He summarizes his work in the form of a table which is reproduced. This table shows clearly which metals can be separated by distillation and which cannot, gives some idea as to the extent of separation, and shows which separation product is in the condensate and which in the residue. The results in the table may also be checked by comparison with the reproduced chart. For example, from the table one sees that nickel and iron cannot be separated by distillation. The reason for this is clearly shown in the chart where it is seen that the vapor pressure curves of Fe-Ni lie very close together.

A clear recognition of the role of vapor pressure in the technology of metals often provides the clue which makes for better understanding of the mechanism of many processes. It is to be hoped that the data in this chart will be amplified by future work to include alloy systems and that the reliability of data on higer boiling metals will be improved. In this connection Leitgebel[16] has published some work on the boiling points of a few lower boiling binary alloys.

Table of Purification of Metals by Distillation

Extent and Type of Separation	Base Metal	Impurities Removed
1 Separation almot complete. Impurity in distillate	Be	Ca, Ba, Mg
	Fe	S, P, Cu, Mn
	Cu	Ag, Bi, Pb, Zn, Cd
	Al	Mn, Zn, Mg, Na
2 Separation almost complete. Impurity in residue	Fe	W
	Be	C, Fe, Ni
	Cu	Au
	Al	Fe, Ti, Cu
3 Separation incomplete. Impurity in distillate	Ni	Cu
	Fe	Cr
	Cr	Al, S
	Cu	S, Sb
4 Separation incomplete. Impurity in residue	Ni	Cr
	Fe	Ni, Co, C, Si
	Be	Bi
	Al	Si
	Cr	Fe
	Cu	NiO_2
5 No separation. Impurities equally divided between residue and distillate	Ni	Fe
	Be	Al, Mn
	Cr	Si
	Cu	Fe, As, Sn
	Ni	Co

References

1. A. G. Robiette. "Electric Melting Practice." J. B. Lippincott & Co. pp. 110-122 (1935).
2. R. Genders and G. L. Bailey. "The Casting of Brass Ingots." British Non Ferrous Metals Research Assoc. p. 108 (1934).
3. J. Chipman. Trans. A.S.M. *22*, 429 (1934).
4. Inorganic Chemistry. J. W. Mellor. Longmans Green & Co. vol. 4, p. 411 (1929).
5. See Ref. 4, p. 420.
6. See Ref. 4, p. 700.
7. S. L. Hoyt. Metals & Alloys *6*, 13 (1935).
8. W. Leitgebel. Metallwirtschaft *14*, 267-270 (1935).
9. See Ref. 3, p. 403.
10. G. R. Fonda. Phys. Rev. *21*, 343 (1923).
11. I. Langmuir. Phys. Rev. *2*, 329 (1913).
12. H. A. Janes, I. Langmuir and G. M. J. Mackay. Phys. Rev. *30*, 20-214 (1927).
13. S. Umbreit. Metals & Alloys *6*, 273-279 (1935).
14. H. E. Bakken. Patents No. 1,594,344 and 1,594,345. Also Chem. & Met. Eng. *36*, 345 (1929).
15. W. Kroll. Metal Industry, London, *47*, 3-6, 29-32, 103-106 (1935).
16. W. Leitgebel. Zeit. anorg. Allgem. Chem. *202*, 305-324 (1931).

Since this article was written, two articles by A. Eucken have appeared in *Metallwirtschaft*, Vol. 15, Jan. 10, 1936, pages 27-32; Jan. 17, pages 63-68. In the first article Eucken makes a critical survey of methods used in making vapor-pressure measurements and discusses theoretical formulas relating vapor pressure with characteristic constants of the metals. In the second article he reviews experimental results on 29 metals. These articles supplement the review by Leitgebel[8] and contain an excellent bibliography.

Trends in American Alloy Steel Production

By EDWIN F. CONE

A STATISTICAL REVIEW of the trends in the production of alloy steels by American steel companies was published in METALS AND ALLOYS for November, 1935. It analyzed the annual data of the American Iron and Steel Institute from the earliest records through 1934. Just recently the institute has issued its statistics of steel production for 1935 and it is now possible to compare the status of the alloy steel industry for 1935 as reflected by these statistics, with its course during earlier years.

Percentage of Alloy Steel of Total Steel Output

The data for alloy steel production and their relation to the total steel ingot and casting output are assembled and analyzed in Table I and Fig. 1. These cover a period of 27 years which is approximately the age of the American alloy industry. It will be noted that in 1935 there was produced 2,119,658 gross tons of ingots and castings as compared with 1,612,275 tons in 1934. This is an increase of 507,383 tons or 31.4 per cent for 1935. The increase in 1935 over 1934 of 65,092 tons was only 4.2 per cent, so that the actual expansion in tonnage last year was of decided proportions.

In percentage of the total steel production of 34,092,594 tons the 1935 alloy steel output of 2,119,658 tons was 6.22 per cent. This compares with 6.19 per cent in 1934 for the 1,612,275 tons of alloy steel produced—a slight increase for last year.

Tons of Total Steel to One Ton of Alloy Steel

There is some interest and significance in a compilation of the tons of total steel produced to one ton of alloy steel. This compilation is found in column 4 of Table 1. In 1934 there were 16.1 tons of total steel made for each ton of alloy steel. In 1935 this proportion was the same, there having been no relative change, one keeping pace with the other. Twenty-

Table 1.—Production of Alloy Steel Ingots and Castings in United States—Gross Tons

	Total Alloy Steel	Total Steel	Per Cent Alloy Steel	Tons of Total Steel to 1 Ton of Alloy Steel
1909	181,980	23,955,021	0.75	131.6
1910	567,819	26,094,919	2.17	45.9
1911	481,459	23,676,106	2.03	49.1
1912	792,501	31,251,303	2.53	39.4
1913	714,357	31,300,874	2.28	43.8
1914	646,953	23,573,030	2.75	36.3
1915	1,021,147	32,151,036	3.17	31.4
1916	1,362,615	42,773,680	3.18	31.3
1917	1,644,335	45,060,607	3.65	27.4
1918	1,787,852	44,462,432	4.02	24.8
1919	1,481,188	34,671,232	4.27	23.4
1920	1,660,292	42,132,934	3.94	25.3
1921	809,548	19,783,797	4.10	24.3
1922	1,673,496	35,602,926	4.70	21.3
1923	2,106,489	44,943,696	4.70	21.3
1924	2,026,409	37,931,939	5.35	18.7
1925	2,432,973	45,393,524	5.36	18.6
1926	2,463,414	48,293,763	5.10	19.6
1927	2,531,748	44,935,185	5.59	17.7
1928	3,214,909	51,544,180	6.23	16.0
1929	3,957,207	56,433,473	7.01	14.2
1930	2,443,311	40,699,483	6.00	16.7
1931	1,455,913	25,945,501	5.61	17.8
1932	798,604	13,681,162	5.84	17.1
1933	1,547,183	23,232,347	6.66	15.0
1934	1,612,275	26,055,289	6.19	16.1
1935	2,119,658	34,092,594	6.22	16.1

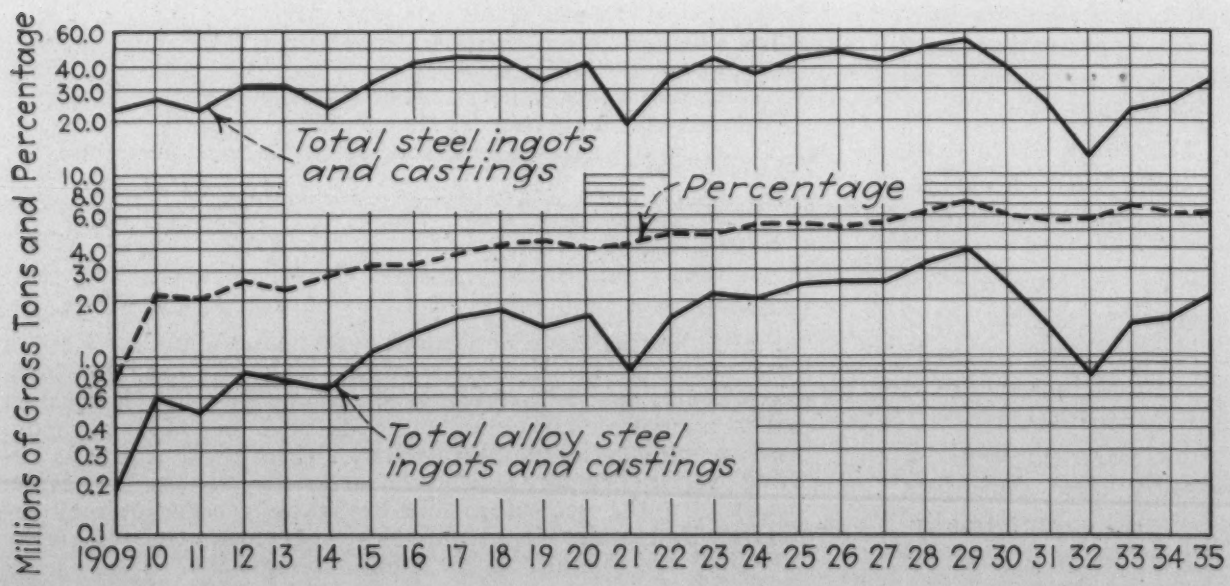


Fig. 1. Relation of Alloy Steel Output to Total Steel Output for 27 Years.

seven years ago, or in 1909, there were 131.6 tons of steel produced for each ton of alloy steel. The best showing was made in 1929 when only 14.2 tons of total steel to one ton of alloy steel were made.

During the six years since 1929, most of this involving the period of the depression, the average has been 16.5 tons of total steel to one ton of alloy steel. This ratio compares with one of 17.5 tons for the six years ended with 1929, or 1924 to 1929. Thus the record of the alloy steel industry in 1935 and during the depression has been an enviable one, judged on the basis of the institute's statistics.

New Record in Electric Alloy Steels

An analysis of the data for electric alloy steel shows that a new record was made in 1935. These statistics are assembled in Table 2 which shows that in 1935 there were 412,563 tons of alloy steel made in electric furnaces. This is 19.46 per cent of the total alloy steel output last year of 2,119,658. It compares with 19.18 per cent in 1934—a record up to that time. In fact there has been a continual expansion in this grade of steel, not only during each year of the depression, but since 1921 when the percentage was 7.81 per cent. Even in the low year of the depression—1932—the amount of electric alloy steel of the total alloy steel was 17.65 per cent, a record at that time.

Table 2.—Production of Alloy Steels Made in Electric Furnaces in United States—Gross Tons

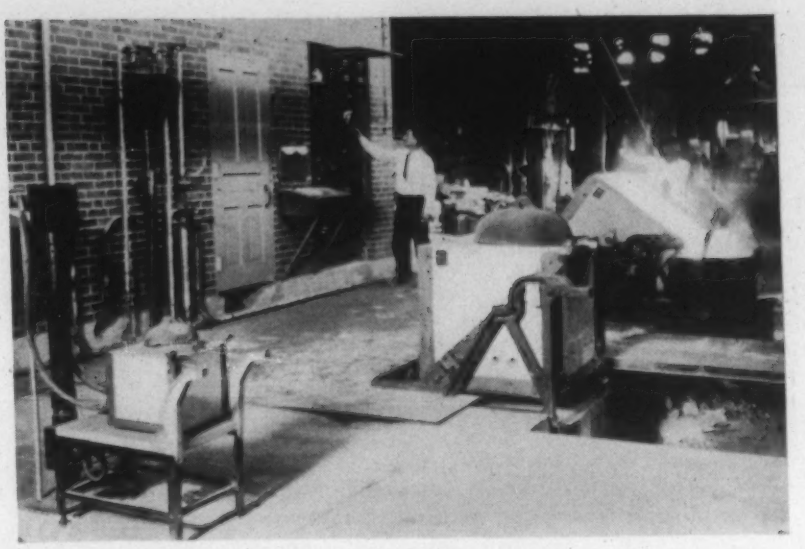
	Electric Alloy Steel	Total Alloy Steel	Per Cent of Electric Alloy Steel of Total Alloy
1909	.....	181,980	....
1910	608	567,819	0.11
1911	.....	481,459	....
1912	9,619	792,501	1.21
1913	11,264	714,357	1.57
1914	9,344	646,953	1.44
1915	27,944	1,021,147	2.73
1916	71,129	1,362,615	5.22
1917	130,578	1,644,335	7.94
1918	290,961	1,787,852	16.26
1919	181,632	1,481,188	12.26
1920	245,572	1,660,292	14.78
1921	63,246	809,548	7.81
1922	125,419	1,673,496	7.49
1923	194,976	2,106,489	9.25
1924	188,563	2,026,409	9.30
1925	293,780	2,432,973	12.00
1926	306,811	2,463,414	12.45
1927	343,517	2,531,748	13.57
1928	433,096	3,214,909	13.47
1929	510,030	3,957,207	12.87
1930	300,520	2,443,311	12.51
1931	232,113	1,455,913	15.94
1932	140,877	798,604	17.65
1933	296,210	1,547,183	19.11
1934	299,236	1,612,275	19.18
1935	412,563	2,119,658	19.46

A reproduction of the institute's data for alloy steel ingots and castings is of interest as showing definite trends over the last four years. The statistics are given in Table 3 for the last three years.

Table 3.—Output of Alloy Steel Ingots and Castings by Processes

Process	Gross Tons 1932	1933	1934	1935
Basic Open-Hearth	616,719	1,169,255	1,278,343	1,633,541
Acid Open-Hearth	27,236	57,097	34,540	73,400
Bessemer	13,651	24,519	53	.....
Crucible	121	102	103	154
Electric	140,877	296,210	299,236	412,563
Total	798,604	1,547,183	1,612,275	2,119,658

Because the data for 1934 and 1935 include only castings made in foundries operated by companies producing steel ingots, they reflect the large increase in electric alloy steel ingots. The production of 412,563 tons in 1935 was nearly three times that in 1932, and 40 per cent in excess of 1934. This expansion in the electric alloy steel output is in large measure explained by the increased use in industry of the chromium and nickel-chromium corrosion and heat resisting steels.



Making Special Alloy Steels in High Frequency Furnaces at Lebanon Steel Foundry.

More Data Needed

The progress of the alloy steel industry as a whole is due of course to the increased number of alloy steels available to industry. The statistics of the institute reflect this expansion but do not tell the whole story. Previous to 1934, the data did include the total steel casting production, but since then only a small proportion of the actual production of alloy steel castings is included—only the output of ingot producing companies which operate foundries. Thus an inadequate picture is presented by these data.

To secure a complete record of the alloy steel industry as a whole, it would be necessary to supplement the institute's data with those of the Steel Founders' Society of America and of the Alloy Casting Association. Unfortunately these statistics are not available for public presentation. Were they available it is fairly certain that the analysis, presented in this review and based only on the institute's data, would reveal an even better showing for 1934 and 1935.

Again it should be stressed that a factor of vital importance is the collection of the data on the basis of a definite and generally accepted definition of what an alloy steel really is. With the advent of the low alloy high-elastic steels, this phase of the statistical situation is becoming more complicated and unsatisfactory. It is definitely assured, however, that the use of alloy steels of all kinds—low and high alloy, simple and complex—is growing rapidly. But a real statistical picture is not available.

Tapping a Heat of Alloy Steel from an Electric Arc Furnace.

Poetry For Metallurgists

IN THE March issue of METALS AND ALLOYS there was published a page of poems which were considered of interest to metallurgists. Our attention has been called to another example of this nature from the pen of L. Gerard Firth, president and general manager, the Firth-Sterling Steel Co., McKeesport, Pa., which we are glad to publish.

Theory and Practice

The Practical Man or the Technical Man—
  Which has the right to boast
That he is the one that brings success,
  That Industry needs him most?

The driving wheel or the steering wheel,
  Ignition or carburetor,
Which is the most essential part?
  Which would you call the better?

Airman, gunner or engineer—
  Which do you think did more?
General Staff or infantryman—
  Who was it "won the war"?

If by a chance you had the power
  To fashion yourself again,
Would you omit your arms and legs
  And put in an extra brain?

Then let us forget this foolish talk
  Of "whom do we most require";
Why—the Technical Man and the Clerical Man
  And the Practical "Man at the Fire"!

FOR the "Metallurgical Poet's Corner" we have two more poems from the pen of L. Gerald Firth, president and general manager of the Firth-Sterling Steel Co. One is "The Roller," a comparatively new one, and the other is "Science Simplified for Steel Works Stenographers" which we reprint as suggested by Prof. William Campbell when, in the March issue, we printed his poem for metallurgists.

The Roller

"I'm glad to meet you," the Roller said
And shook the Customer's hand.
"Excuse me a minute, I have to loosen
The screw in the finishing stand.
You are the fellow who wants his steel
O thirty-eight exact;
You also complained it didn't blank
That four in a thousand cracked."

"You think a little bit extra care
Would make the size come right
And it's only a question of setting the rolls
And keeping the screws down tight
That might be true in a cogging mill
But if you'll stop to think,
There must be a limit to what can be done
And yours is on the brink."

"You may be running on 19 gauge
When a neck gets over hot,
In half a jiffy you've lost your size
For the roll expands a lot;
Then you've got to jump or the screws will jam
And if they can't be turned,
Before you can stop the mill she sticks
And the roll is badly burned."

"Now here is an order that must be soft
Or else they'll send it back,
And this 'must be rolled extremely fast
Or otherwise it will crack'
And here's another that 'has to give
Brinell two seventy-two,
It's very important to cool it slow'.
And they add—'That's up to you'."

"Now here is an order for Stainless Steel
Of two by nineteen gauge.
It must be kept three thousandths scant
Or the boss is sure to rage;
And here's some more, a couple of tons
Of three by O five eight,
'Hold two to seven thousandths full
And *absolutely* straight'."

"I've worked on a mill for forty years,
As a roller thirty two,
But never can feel I know my job
For there's always something new,
And I'm always doing what 'can't be done'.
Don't think I want to complain
But I like my work to be right—Good Bye,
Come round and see us again."

Science Simplified for Steel Works Stenographers

I assume in the beginning
  You are all aware that 'twinning'
Has an allotropic form in Newmann Bands,
  And the phenomenon of 'slip'
  In cold distorted strip
Is something everybody understands.

It was controversial, quite,
  As to what was martensite
Until Jeffries and Archer took the case,
  It is ferrite, they surmised
  Finely grained and crystallized
Having body centered lattices in space.

Now Arnold still insists
  That martensite consists
Of a carbide holding ferrite in suspension.
  While the needles, Osmond feels,
  Seen in martensitic steels
Are pseudo-morphs of twinnings due to tension.

Now next I will explain
  That each individual grain
Is anisotropic—then I will relate
  How this anisotropic grain
  In the mass will give again
A pseudo-isotropic aggregate.

If a liquid isn't pure,
  When solidified, it's sure
(An eminent professor so insists)
  To show some indication
  Of dendritic segregation
Since heterogeneity exists.

Dr. Rosenhain proclaims
  That on cooling there remains
An amorphous inter-crystalline cement
  While distortion of the lattice
  Causes hardening, and that is
Because adjacent atoms will be bent.

Now it's interesting I think
  That zirconium and zinc,
With lattices hexagonal close-packed,
  If distorted when they're cold
  (By Jeffries we are told)
Are tolerably certain to be cracked.

While iron, he relates,
  In its alpha and beta states,
Has body-centered lattices, and though
  It should be rank futility
  To look for good ductility
Yet curiously enough it isn't so.

WE welcome another contribution to the "Metallurgical Poetry Page" from Fred P. Peters, chief chemist, Wilbur B. Driver Co., Newark, N. J., on a spectre which has been haunting him too frequently. It follows:

The Spectre of Davenport Archer Gillett, McCarthy McQuaid-Ehn Sauveur

After I've finished my work and go home
To hunt for the facts I should know,
I tremble to think of the close of the day
When off to my bed I must go.

For I have a banshee that visits me oft,
When only the owls are astir.
'Tis the spectre of Davenport Archer Gillett
McCarthy McQuaid-Ehn Sauveur.

This composite wraith wears a Shavian beard
Which he bleaches with HNO_3.
And because it is white, it must be cementite,
Was his first dismal lecture to me!

Inside it he carries an old microscope
Which—he points out again and again—
Must be handled with care and protected from air,
For it serves him in place of a brain.

I shrieked when I first saw his *two crystal eyes*
But he warned me those words to eschew—
His original sin made him all crystalline,
So "to crystallize" must be taboo!

On austenite grain size he lectures for hours,
'Tho unable at times to recall,
When performing the test, if it wouldn't be best
Not to add any carbon at all.

He'll shatter my slumber by beating his breast
(Which rings like the Liberty Bell)
And in accents metallic, with sarcasm gallic
The New Dealers' virtues he'll tell.

Oh, where are the sweet dreamless nights that I knew
When no interest in metals had I—
'Ere I started to crack all the books on the rack
And their wisdom I sought to apply?

For this pale, haggard face and these dull, vapid eyes,
And these jitters are caused, I aver
By the spectre of Davenport Archer Gillett
McCarthy McQuaid-Ehn Sauveur!

LETTERS TO THE EDITOR

New Terminology - "Liquidoid" and "Solidoid"

To the Editor: When an author includes in a textbook some original matter, or at least some matter about which he should like to have the criticism of his readers, he is not likely to hear from them.

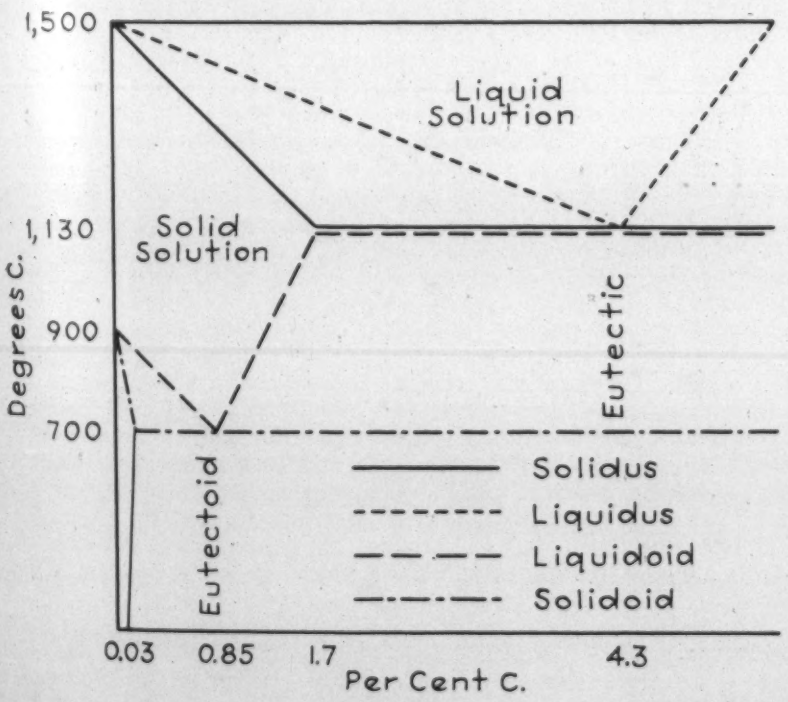


Fig. 409

On the other hand, such matter, when included in a paper presented to some society, or in a periodical, generally receives the attention the author desires.

This thought leads me to present to you a diagram with its explanation, as quoted from the last edition of my book "The Metallography and Heat Treatment of Iron and Steel" in the hope that, should you decide to publish it, some of your readers may express their opinion regarding the advisability of the use of these terms, namely "liquidoid" and "solidoid."

Sincerely yours,
Albert Sauveur.

Harvard University
Cambridge, Mass.

In the illustration, Fig. 409, the author ventures to coin two new words: "liquidoid" to indicate the beginning of the formation of a new phase from a *solid* solution, suggestive of liquidus which refers to the beginning of the formation of a solid phase from a *liquid* solution, and "solidoid" indicating the end of the phenomenon suggestive of solidus which marks the end of the solidification. The meeting point of the liquidus curves indicate the formation of a eutectic, whereas in a similar manner the meeting point of the liquidoid curves indicate the formation of a eutectoid.

Random Thoughts on Definitions

To the Editor: Your item about the lady and puddled steel in the April issue of METALS AND ALLOYS ["A Laywoman's Picture of the Steel Industry," page 101] reminds the writer that both of America's leading dictionaries define semisteel as puddled steel (U. S.). They also state that silver steel is an alloy of steel containing a very small amount of silver. I wonder if the manufacturer of silver steel tools would agree with this definition.

On the definition of metallurgy either the dictionaries are behind the times or else American manufacturers and trade journals are in error. While textbooks on this subject deal with the extraction of metals from their ores, people refer to the metallurgist in connection with firms which deal solely with the manufacture of metal products from material received in the metallic state. Why not call the laboratory workers metal chemists, or metal physicists, and be scientifically correct in the use of words?

We refer to paint chemists, water chemists, starch rubber, oil, paper, food, etc., chemists, so why call the analyst of metals, a metallurgist which he usually is not?

ALEXANDER LINDSAY

Chicago, Ill.

Progress in the Clarification of Problems in High and Low Temperature Uses of Metals

DESIGNERS who must appraise the suitability of alloys for service at elevated temperatures, as in oil stills, high pressure steam plants, conveyor mechanisms in heat-treating furnaces, and many other types of service, have two problems: First, finding out what the high temperature properties are, as revealed by suitable tests, and second, deciding upon a proper factor of safety for the service in question. The second remains their own problem, but material aid is being given in respect to the first through the work of the A.S.M.E. and A.S.T.M. in their Joint Committee on Effect of Temperature on the Properties of Metals.

This committee has been established for a dozen years, in which period it has published over 1300 pages of information. It has sub-committees comprising more than 60 active workers in this field who are developing reliable methods of evaluating both high and low temperature properties, and are applying those methods to the study of alloys of commercial importance. Although the time factor has such an influence in the stability and load carrying ability at high temperatures that many phases of the work are very tedious and expensive, requiring special equipment and meticulous attention to detail, a constant flow of results is being obtained, which are reported each year in June at the A.S.T.M. meeting and in December at the A.S.M.E. meetings.

Due to insufficient knowledge as to the effect of the time factor and as to the necessary precautions for obtaining concordant and reliable results, much of the earlier data in the technical and advertising literature is unreliable and misleading, and good data are scanty because of the cost of obtaining them, so that when the designer looks in his handbooks, or in the more specialized literature, he is dismayed by the general lack of information and by the discrepancies in published information, and is impressed by the insecurity of extrapolation from even tests of several thousand hours duration to the much longer periods of actual service.

In a field where the alloys required are often costly and their service of a type involving fire or explosion hazard, this situation certainly calls for the sort of attention the Joint Committee is giving it.

Due to the efforts of the committee, great strides have been made in codification of testing methods so that one may be sure that when tests are made according to best practice, differences observed between materials are truly differences in materials and not in test methods. This is facilitated by the availability of a specially selected lot of steel whose long and short time, high and low temperature properties are being very thoroughly explored in the work of the committee, and which is available to interested parties for checking their own laboratory methods. Full information on the results obtained in such check tests is the only recompense required by the committee. The problem of extrapolation is being attacked by carrying out tests of 3 yrs. duration, which are now well advanced, upon typical ferritic and austenitic steels, as well as by continued attention to the basic problem of stability.

The Joint Committee, through its own committees, its related sub-committees, and its individual members, has been cooperating with A.S.T.M. committees that develop specifications and with various committees of the A.S.M.E., for the purpose of assisting engineers to purchase suitable materials and to use reliable data when designing steel parts to be placed in service at high temperatures. Thus far the Joint Committee's work has resulted in high temperature test data only on a few selected steels.

At a recent meeting, the Joint Committee decided to attack the more general problem of listing all for alloys, whether or not classified today as commercial, such temperature test data as are deemed reliable. Because this task cannot be accomplished promptly by the spare-time attention of the Joint Committee and sub-committee members, and because there is a great present need for assembling and publishing reliable information of this kind, the Joint Committee voted to employ a skilled investigator to get to work at once on this task under the direction of the committee headed by P. E. McKinney.

One pressing problem for industry lies in the need for accurate data that are typical of the properties of various alloys placed in high temperature service. The primary purpose of a research group such as the Joint Committee, is to perfect testing methods and to study the behavior of typical materials, so that a method of attack can be developed for use by producers and consumers in solving their own specific problems. This type of testing work in the field of high temperatures is very expensive, and it is necessary to use extreme precautions to avoid the danger of getting data that, instead of serving the purpose, actually mislead the engineer. There are a few laboratories, outside of those represented on the Joint Committee and its sub-committees, which are prepared to deal properly with such problems. However, the list of laboratories using satisfactory equipment and methods fortunately is increasing steadily.

It may not be generally known that the Joint Committee has recognized its responsibility to industry along the lines just mentioned. As a matter of fact, the Joint Committee (beginning with 1933) has offered to plan and execute for each of several industrial groups, experimental work to ascertain the high temperature properties of specific alloys for specific purposes, provided that the group would adequately finance the work, and would be willing to have the testing done along lines that are believed by the Joint Committee to be dependable. No such specific problems can be undertaken unless the interested group will authorize sufficiently comprehensive studies to favor the accumulation of reliable data. Because there is serious need for such data by engineers in connection with a specific grade of metal generally believed to have service possibilities at high temperatures, the Joint Committee freely places at the disposal of properly organized industrial groups, the collective experience of its members, under the conditions that have just been explained.

The committee's own direct work will continue to be oriented along fundamental lines, primarily seeking further information on the control of stability and the development of test methods of engineering applicability, through work on materials chosen as typical, rather than attempting themselves to determine the properties of every alloy that may be suggested. Several new fields of experimental activity are under discussion, among them being evaluation of low temperature properties—a matter already being surveyed by a sub-committee—study of methods of determining resistance to oxidation, relation of tensile properties to the stresses obtaining in tubes in service, etc. Definite plans will be laid at a committee meeting the latter part of June. Suggestions from those interested in the high and low temperature fields as to topics which should receive early experimental attention will be appreciated, and if sent to the Secretary of the Joint Committee, N. L. Mochel, Westinghouse Electric & Mfg. Co., Lester Station, Philadelphia, in time, they will be brought before the committee at its June meeting.

The new projects will be in addition to the 3-yr. test program now in progress, and to the continual effort to improve testing methods. The number and scope of the new projects will depend upon the financial support afforded by industry.

While the financial resources will not be known till the final report of the finance sub-committee, headed by Major R. A. Bull, 541 Diversey Parkway, Chicago, preliminary returns indicate that several new lines of experiment can be undertaken. Hence the committee is anxious to get the opinion of industry as to what new projects should have preference in the order of attack.—H. W. Gillett, chairman, Sub. Com. on Publications.